Walter Leal Filho
Editor

Handbook of Climate Change Adaptation

Springer Reference

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With 362 Figures and 260 Tables

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Foreword

Climate change is one of the most pressing challenges mankind currently faces, being a matter of great concern to people living in both industrialized and developing countries. Due to its scope and its implications to the economy of countries, to properties, and to human health and well-being, it is essential to make sure that we are able to adapt to climate change.

But even though the need for adaptation is a perceived one and in many parts of the world, urgent action in the field of climate change adaptation is needed, there is a paucity of scientific publications which tackle the subject matter of climate change adaptation in a holistic way.

In an attempt to address this problem and at the same time provide a contribution to foster a better understanding of the various aspects of climate change, the International Climate Change Information Programme (ICCIP)—in cooperation with Springer—have prepared this landmark multivolume reference work. This handbook is aimed at fostering a broader understanding of what climate change is, what it means to people, and how its impacts on the environment and ecosystems can be reduced via climate change adaptation strategies.

Consistent with its editorial aims, this Handbook is structured along four parts:

Part I. Climate Change Impacts and Management (handling climatic, physical, human, and biodiversity impacts on land and water ecosystems)

Part II. Policy and Climate Change (handling policy measures, planning procedures, and concrete action to cater for adaptation efforts)

Part III. Climate Change Adaptation, Agriculture, and Water Security (handling concrete examples of adaptation efforts in the field of agriculture and water capture, storage, and use)

Part IV. Climate Change Adaptation Technologies (presentation of examples of technologies which allow adaptation to be pursued and implemented in the short and medium term)

A set of cross-cutting issues have been included across all parts, such as the socioeconomics of climate change, resilience, trade, growth, development, justice, poverty, health, populations, security, international politics, the UN process, democracy, education, as well as information and communication. Although the

Handbook is on the one hand grounded in the best science and meets the highest scientific standards, it aims on the other hand to be inclusive methodologically and be practice based.

Specialists from across the world have provided a wide range of contributions addressing many of the variables associated with climate change adaptation with examples, case studies, and projects from all geographic regions. Their efforts are commendable since their willingness to document and disseminate their ideas, approaches, and projects via this Handbook makes it a very rich publication.

I want to thank all the authors who contributed to this Handbook for their time and effort. It is hoped that this Handbook may not only be used as a tool toward the greater understanding of different variables associated with climate change adaptation.

All in all, we have managed to produce a groundbreaking publication, which will hopefully provide practical assistance and support to climate change adaptation initiatives across the world. We also hope that it may serve as inspiration and guidance to many others, helping to tackle a problem which is global in its scope but often local in its impacts.

Walter Leal Filho
Editor-in-Chief

About the Editor

Professor Walter Leal (BSc, PhD, DSc, DPhil, DL, DLitt, DEd) is Professor and Head of the Research and Transfer Centre Applications of Life Sciences at the Hamburg University of Applied Sciences in Germany and holds the Chair of Environment and Technology at Manchester Metropolitan University, UK. He is a Review Editor at Working Group II (Climate Change Adaptation) at the Intergovernmental Panel on Climate Change (IPCC) and founding editor of the *International Journal of Climate Change Strategies and Management* and heads the International Climate Change Information Programme (ICIIP). He is also Editor-in-Chief of the *Climate Change Management* series with Springer.

Prof. Walter Leal serves on the editorial board of various journals. He has in excess of 300 publications to his credit, among which are groundbreaking books such as *Universities and Climate Change*, *The Economic, Social and Political Aspects of Climate Change*, and *Climate Change and Disasters Management*. He teaches environmental management, information, and climate issues at various European universities. He has over 20 years of research experience on all aspects of environmental information and education and has a particular interest in the connections between environmental management, sustainability, climate, and human behavior.

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Justice Nyamangara is a Soil Scientist with a B.Sc. Agriculture Honours from University of Zimbabwe, M.Sc. Soil Science from University of Aberdeen (UK), and a Ph.D. in Soil Fertility and Environmental Pollution from the University of Zimbabwe. He is currently Professorial Chair of Environmental Science at Chinhoyi University of Technology (CUT) (Zimbabwe). Professor Nyamangara has also worked as a Scientist at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (2009–2014), Visiting Scientist at the International Center for Tropical Agriculture (CIAT) (2007–2008), Associate Professor and Deputy Dean of Agriculture at the University of Zimbabwe (2000–2009), and Principal Research Officer and Head of Crop Nutrition at the Department of Research and Specialist Services (Zimbabwe) (1990–2000). His research focuses on soil fertility, conservation agriculture, climate change, and environmental pollution. He has supervised or cosupervised more than 20 postgraduate theses, and has in excess of 100 publications to his credit.

Anirudh Singh is Associate Professor at the University of the South Pacific (USP) within the School of Engineering and Physics. He teaches courses in renewable energy and basic physics and leads the regional component of a multinational project in renewable energy. His research interests are renewable energy and climate change, with specific interest in the areas of biofuels, energy efficiency in buildings, and energy policy. His most recent publications include four book chapters in renewable energy and a perspective paper in biofuels. He is currently supervising one Ph.D. and three M.Sc. students.

L. Vargas received an Electrical Engineer diploma and an M.Sc. degree from Universidad de Chile, Santiago, in 1985 and 1987, respectively, and a Ph.D. degree in 1994 in electrical engineering from the University of Waterloo, Waterloo, Ontario, Canada. Since 1994, he has worked at the Electrical Engineering Department, Universidad de Chile, where currently, he is Associate Professor. Dr. Vargas has been involved in applied projects for the main electric companies and energy institutions in Chile as well as international agencies. His main research interests are in the areas of wind energy, supply and demand forecasting, regulation, and expansion planning of energy systems.

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Thanks are also due to the section editors for their hard work and support in checking all papers and for overseeing the revisions of the manuscripts. Their help was important and most appreciated.

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Part I

Climate Change Impacts and Management

A Methodological Framework for Building an Index for Vulnerability Assessment in Rainfed Agriculture

Aliou Diouf and Amadou Thierno Gaye

Contents

Abstract

This chapter presents a methodological framework to build an index for participatory vulnerability assessment of rainfed agriculture in Ngayokheme rural community, Senegal. Through a participatory approach, the chapter identifies components/resources of rainfed agricultural system, evaluated their exposure, sensitivity, and adaptive capacities to climatic and non-climatic stressors. A review of the main vulnerability indices developed in the literature highlighted gaps. And based on the weaknesses of the existing indices, a new index combining exposure, sensitivity,

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and adaptive capacities is proposed. A tool for vulnerability assessment replicable in different contexts and accessible to all disciplines has been built. The vulnerability of the whole system of rainfed agriculture as well as each of its components was quantified using a participatory approach. The chapter attempts to provide a detailed framework for assessing vulnerability to climate change of the rainfed agriculture, in such a manner that all countries of the region can follow it. Climate change is affecting rainfed agriculture in Senegal. To mitigate impacts of climate change and increase the resilience of the sector, a good vulnerability assessment is required. This is why an index for assessing vulnerability to climate change of the rainfed agriculture has been suggested. This focused on strengthening the vulnerability evidence base to support climate change policy, advancing knowledge and training to understand climate change impacts, and implementing adaptation measures. The framework presented on this chapter could yield substantial benefits for Senegalese and other Sahelian countries.

Keywords
Index • Vulnerability • Assessing • Participatory approach

Introduction

The adverse effects of climate change on natural and human systems are becoming more and more severe and complex. This is why the question of understanding the level of vulnerability of natural and human systems has become a major concern and a challenge for the academic, political, and development practitioners' communities. Several studies on vulnerability analysis have been undertaken. Many of them were performed using the participatory approach. The participatory approach has emerged with the "Activist Participatory Research" during the 1960s. Ever since, several variants of participatory approach have been developed. Thus, in the 1970s, variants such as "Field Research on Farming Systems," "Participatory Research (PR)," "Rapid Rural Appraisal (RRA)," and "Agro-ecosystem Analysis" have emerged. Later, in the 1980s, other variants of the participatory approach were developed and strong. Thus, "Applied Anthropology" and "Participatory Rural Appraisal (PRA)" have emerged. The 1990s saw the emergence of Participatory Action Research (PAR) (Chambers 1994). The participatory approach has been experimented, initially in developing countries' rural areas, and has enabled community to share their perceptions and identify, prioritize, and appraise issues from their knowledge of local conditions (Rabinowitz 2013; Van Aalst et al. 2008). A participatory approach is a process in which every stakeholder in the intervention has a voice. Everyone who has a stake should be invited to the table. In a participatory approach, all stakeholders' voices are heard and respected and that everyone has some role in decision-making (Rabinowitz 2013).

Researches that have used participatory approach have proved useful because they have informed on how natural and human systems are vulnerable to climate hazards. However, these studies have failed to meet the needs of academia, policymakers, and practitioners to quantify the vulnerability in order to understand its severity level and plan responses to climate change effects.

To fill this gap, researches to quantify vulnerability to climate change have been made. The modelers have undertaken most of them and limited vulnerability assessment to analysis of climate change impacts on a number of sectors such as agriculture, health, water resources, forests, etc. However, these studies had shown some limitations related to the fact that impacts of climate change are measured on a limited number of parameters although studies generally focused on systems. So, understanding the vulnerability of such a system cannot be reduced to impact of climate change on few elements of the system. In addition, social, cultural, economic, and political aspects are barely considered in these models. This is why studies using modeling do not give a full measure of the vulnerability of a system.

In recent years, we have witnessed emergence of new studies trying to combine qualitative and quantitative approaches to vulnerability. These studies are to quantify the vulnerability using the participatory approach. They seek, through community participation, to provide a quantitative measure of vulnerability and to explain it. These researches are based on the definition of a conceptual framework that allows them to start identifying determinants or parameters of vulnerability. These studies propose models of relationship between parameters of vulnerability to calculate the value of the vulnerability and produce vulnerability indices.

According to the definition of vulnerability, several types of model relationship between the determinants have been proposed. However, most models that establish relationship between determinants of vulnerability do not accurately express the link between these determinants. Many models build on subtraction or addition relationship or combine both. However, these two types of relationship do not sufficiently reflect the relationship between the determinants of vulnerability. This arises the following question: which model faithfully expresses the relationship between the determinants of vulnerability?

The aim of the present chapter is to feed thought and efforts made to construct appropriate vulnerability index. More specifically, the present chapter proposes a methodological framework for building an integrated index to assess vulnerability to climate change of rainfed agricultural system in Senegal through a participatory approach. To do this, a review of approaches to vulnerability will be made in the first place. This review will be followed in a second phase of a critical analysis of computational models of vulnerability. In a third step, a model of the relationship between the various determinants of vulnerability will be offered, followed by a description of the methodological framework to construct the index of vulnerability.

Review of Vulnerability Approaches and Indexes

Climate change mainly is manifested in adverse effects on livelihoods in developing countries that are most vulnerable. The effects are often complex and difficult to understand. The need for understanding vulnerability justifies that of analysis and assessment of vulnerability.

Vulnerability has been abundantly analyzed and defined, especially in the climate change literature (Luers et al. 2003; Füssel 2009). However, first definitions arose from geography and ecology (Cutter 1996). Timmermann (1981) has provided to the scientific community with the first reference definition of vulnerability. He defined vulnerability as "the degree to which a system acts adversely to the occurrence of a hazardous event. The degree and quality of the adverse reaction are conditioned by a system's resilience (a measure of the system's capacity to absorb and recover from the event)." But it is in risk and disaster management and recently in environmental change and in development and environment areas that the word vulnerability is mostly used. Indeed, during the past two decades, the concept of vulnerability acquired an important place, especially with the IPCC Assessment Reports. Owing to the abundance of the analysis of the concept, further work on vulnerability assessment, including approaches, methods, and tools, had been undertaken and several conceptual and methodological approaches of vulnerability have been developed (Cutter 1996).

Despite this important scientific production, fundamental conceptual differences remain about definition and approaches of vulnerability. Broadly, there are three major schemes of vulnerability frameworks. The first one distinguishes biophysical and socioeconomic vulnerability (Füssel 2009). The second scheme recognizes external factors *that are not part of the system* and internal factors *that are part of the system.* A third scheme that can be presented as the most comprehensive deals with vulnerability as contextual (starting point) and vulnerability as an outcome (end point) (O'Brien et al. 2007; Brooks 2003; Füssel 2009; Kelly and Adger 2000; Turner et al. 2003 ; Maru et al. 2014). The key element on which the focus is put when explaining vulnerability of human or natural systems distinguishes these approaches.

Biophysical Approach

The biophysical approach highlights the key role played by external/natural hazards in the occurrence of vulnerability of human and natural systems. Thus, Gabor and Griffith (1980), Mendelsohn et al. (1994), Polsky and Esterling (2001), and Sanghi et al. (1998) have emphasized how cash income of farmers is affected by natural hazards. Adams (1989), Kaiser et al. (1993), and Olsen, Bocher, and Jensen (2000), Kurukulasuriya and Mendelsohn (2006) also studied the vulnerability of agriculture by linking climate change stressors to agricultural yields. Similarly, Martens et al. (1999) in health sector; Du Toit et al. (2001), FAO (2005), Xiao et al. (2002) in food security and water availability sectors, and Forner (2006) and Villers-Ruiz and Trejo-Vázquez (1997) in ecosystems sector studied climate change effects. All these studies put the focus on natural/external factors as causes of economic, social, agricultural, health, and vulnerability.

This approach has the advantages of providing relevant and measurable information. It helps to know the extent of the impacts of natural hazards on different natural systems. However, this approach often adopts a negativistic, futuristic, and quantitative perspective of impacts of climate change. In addition, this approach often has a negativistic and futuristic perspective of the impacts of climate change. The impact assessment focuses on the damage areas and is based on the predictions of climate models and other agricultural, economic, and health models. Thus, any comprehension of the current vulnerability is provided (Gabor and Griffith 1980). It also gives only quantitative data. Certainly very informative, this approach however does not demonstrate what these impacts mean for communities. For example, 50 % of lower yield due to climate change does not mean the same thing for a Senegalese farmer and for an American farmer. In the same vein, even if development of mosquitoes due to climate change can drive the resurgence of malaria, this increase will not have the same effect for two individuals or communities that have unequal access to health services and monetary income. This physical/natural approach does not take into account the adaptive capacities of systems having been affected by the climatic stimuli.

Social Sciences Approach

This approach emphasizes factors related to the socioeconomic and political status of individuals and communities, in short, the social system, including changes in status between individuals and communities (Füssel 2007, 2009). This approach considers that there are a variety of social status between individuals and between and within communities (Füssel 2007). These differences can be approached through gender, social and political class, education level, wealth, access to health services, natural resources, credit, agricultural inputs, technology, formal and/or informal social capital, etc. (Adger 1999). These factors are major social determinants of vulnerability (Allen 2003; Kelly and Adger 2000). This socioeconomic approach of vulnerability has the advantage of highlighting importance of internal resources available to an individual, a community, and a sector or system to reduce the negative effects of a shock. It shows that an individual, community, or system does not remain inert when it is attacked. It often responds to attacks drawing on its resources. The vulnerability is seen as an internal state of a system before the external forces of nature occur (Allen 2003).

The limitations associated with this approach are related to the low inclusion of natural/external factors. Yet, the role of the latter cannot be ignored when interpreting vulnerability. For example, two communities with similar socioeconomic conditions, but subject to natural hazards of different intensity and frequency, do not have the same level of vulnerability. Although socioeconomic factors are crucial in explaining the vulnerability, neglecting natural factors leads to a partial understanding of the vulnerability. Reconciling the two approaches seems to provide benefits to the full understanding of vulnerability.

Integrated Approach

However, although having obvious benefits in terms of vulnerability assessment, both biophysical and social approaches do not have less limitation from the perspective of an integrated assessment of the socio-environmental dimensions of vulnerability. Reconciling the two approaches seems to be advantageous to take the full measure of vulnerability. This is the main characteristic of the integrated approach that combines both social sciences and biophysical sciences approaches to determine vulnerability (Füssel 2007). In this regard, an adaptation of the IPCC definition of vulnerability can help reconcile the approaches of biophysical and social sciences into an integrated approach. The IPCC defines vulnerability as "the degree to which a system is susceptible to, or unable, to cope with the adverse effects of climate change, including climate variability and extreme weather conditions" (McCarthy et al. 2001, p. 995). While the IPCC definition specified directly to change climate, particularly to climate risks, an integrated approach of vulnerability needs to integrate biophysical and socioeconomic factors in addition to climate risks. The adaptation of IPCC conceptualization integrates internal and external factors and biophysical, socioeconomic, and climatic stressors. Vulnerability according to IPCC depends on the nature, extent, and rate of climate variation to which a system is exposed and the sensitivity and adaptive capacity of the system. The exposure parameter includes external factors, while sensitivity encompasses internal dimension as for adaptive capacity.

An Overview on Vulnerability Index

Based on these approaches, indices have been developed to better quantify and assess vulnerability level. Adger (1996, p. 49) developed a vulnerability index where vulnerability to climate variability is function of social vulnerability and environmental risk:

1. Vulnerability to climate variability = f(social vulnerability, environmental risk)

*where environmental risk can be indicated by the return period of a threshold physical hazard: Environmental risk = Impact * Pr*

where Pr = 1/R (Pr = probability and R = recurrence interval (years)).

Although this index takes into account the natural and social factors, the relationship between the parameters is not clearly established. It considers vulnerability as a function of social vulnerability and environmental risk, but does not clearly indicate the type of relationship between these parameters. In addition, the adaptive capacity parameter is not explicitly taken into account in the calculation of vulnerability. It is not clear whether it lies in social vulnerability or not.

Moss et al. (2001) determined vulnerability index (VI) by assigning a negative value to sensitivity and a positive value to adaptive. They establish relationship between parameters through this equation:

2. Vulnerability = (adaptive capacity)–(sensitivity + exposure)

This equation considers vulnerability as the difference between adaptive capacity and sum of exposure and sensitivity. This relationship model has a number of limitations. The relationship between sensitivity and exposure does not seem to be well translated by an addition as shown in this equation. The addition relationship links two parameters of a similar nature. However, sensitivity is totally different from exposure as sensitivity mainly refers to the internal structure system, while exposure is related to external factors. Also, the order of the parameters in this equation is not appropriate. Before talking about adaptive capacity of a system, it must have been exposed to and affected by a hazard. A system never adapts ex nihilo, it adapts to a hazard. So the exposure and sensitivity should come before adaptive capacity. That is why adaptive capacity should come after in the order of parameters, because it has to be deducted from the exposure and sensitivity, and not the contrary. In addition, the adaptive capacity plays an attenuator or dissolving role of effects of exposure and sensitivity. In this regard, the subtraction is not the best type of relationship.

Yohe et al. (2006) have developed indices of (aggregated outcome) vulnerability to climate change that vary according to different assumptions regarding climate sensitivity, development of adaptive capacity, and other calibration parameters. The aggregated vulnerability is calculated as

3. $Vi(t) = \frac{\Delta Ti(t)}{ACi(t)}$,

whereby $\Delta Ti(t)$ *is the projected change in national average temperature (i.e., a rational-scaled variable) and* $ACi(t)$ *is a normalized index of national adaptive capacity (i.e., an ordinal-scaled variable)* (Brenkert and Malone 2005).

This index has a specific climate and futuristic orientation. The risk in question here is a projected climate risk and is neither a current risk nor a non-climatic risk. Furthermore, the sensitivity parameter which is very important in the vulnerability of a system or sector is not integrated into the development of this index.

In summary, these indexes that have been developed have two main limitations. The first is related to the inappropriate nature of the relationship posed by these indices. The second limitation is related to the fact that these indices do not incorporate both natural and socioeconomic as well as the adaptive capacity of the whole area in question. In short, these indices are not based on a systemic approach of the systems studied. A third shortcoming of the indices is related to the fact that many of them are built for a national level and not do not take into account local specificities.

Methodological Framework for Building an Integrated Participatory Assessment Vulnerability Index

Conceptual Definitions

The development of a new vulnerability index in this study is yet based on the IPCC definition of vulnerability, but goes beyond. It is not focused exclusively on climate change as a hazard, but includes all significant factors that are sources of vulnerability for rainfed system at community level. The IPCC (2007) definition shows that vulnerability depends on three parameters: exposure, sensitivity, and adaptive capacity. However, the relationship between them is not specified (Fussel 2009). Before proposing the relationship between these three parameters and that result in a situation of vulnerability, it is important to make an analysis of these three parameters

Exposure. The first parameter of the vulnerability in the IPCC definition is identified by a group of words, namely, *the nature, magnitude, and rate of climate variations to which a system is exposed*. It is in this expression that the term *exposure* appears. So exposure is closely related to risk and hazard. Exposure is defined as the situation or position to which a system, a sector, a social group, or an individual is within the reach of a hazard. Being exposed is to be not sheltered from a risk; being exposed is to be in a situation where one is potentially reachable by a hazard.

One can note that exposure involves a hazard and a system. To be exposed, there must be a stressor and a stressed object. It also requires that the characteristics, nature, extent, and strength of the stressor allow it to reach the exposed system. However, it should be noted that exposure does not necessarily mean being in danger. People can be exposed without running the risk of being damaged, to see their physical or moral integrity affected. In addition, exposure can be assimilated to risk in the sole condition that there is a possibility of damage to the exposed element.

Sensitivity and impact. The second parameter of the IPCC definition of vulnerability is about sensitivity. Being sensitive is reacting (positively or negatively) if one is affected by an external force. A system is when it reacts and changes state regardless of the time, when it loses its trajectory, its identity, and its natural properties be it temporarily or permanently. Sensitivity is the susceptibility of a system to react, to respond to an attack, change positive or negative when the agent reached it. It mainly depends on the constitution of the internal structure of the system. The sensitivity is very important in the sense that regardless of the strength of a stimulus, if the system has no sensitivity, the stimulus can never be a risk, the system cannot be considered exposed.

Sensitivity is closely related to the impact which is the result of the sensitivity of a system and the nature of the shock that affects the system. The impact is a product of the sensitivity of a system and the intrinsic characteristics of stress (magnitude, force, rhythm, frequency of the stress).

Adaptive capacity. Adaptive capacity is defined as the set of resources available to a system to reduce the negative effects of stressors or to take benefit from them. It is a function of human resources, technology, social and cultural resources, access to information, and institutional, economic and financial, and physical and natural resources.

Vulnerability. Based on these conceptual definitions, it can be noted that the exposure and sensitivity when they increase or decrease tend to produce the same type of effect on a system. Their common growth increases the vulnerability of an element, while their decrease reduces vulnerability. However, adaptive capacity has an opposite effect on the vulnerability. Indeed, when the adaptive capacity increases, it tends to reduce vulnerability and vice versa. The relationship between exposure and sensitivity as well shows that if each increases by one unit, the resulting increase is more than the sum. The relationship is better expressed as a multiplication. Adaptive capacity does not play a role of subtracting the combined value of the exposure and sensitivity, but tends to diminish or invalidate effects produced by exposure and sensitivity. Adaptive capacity acts as divisor of the product formed by the exposition and sensitivity. In this regard, the best relationship that binds adaptive capacity to exposure and sensitivity is a division relationship. The division is the best relationship that leads a factor toward zero.

Given the relationship between exposure and sensitivity on the one hand and between these two parameters to adaptive capacity on the other, we propose to calculate vulnerability using the following formula:

$$V = {}^{E \times S}/_{Ac}$$

where

V = Vulnerability
E = Exposure
S = Sensitivity
Ac = Adaptive capacity

An adaptation of the IPCC definition that incorporates the nature of risks or hazard (continuous or discontinuous hazard) could lead to consider vulnerability as function of the magnitude and rhythm, or force and probability of a hazard, sensitivity, and adaptive capacity of the system.

Approach for Building the Integrated Index

Participatory Evaluation of Parameters of Vulnerability Through Focus Groups

To build the integrated index, the rainfed agriculture has been approached as a system. Our unit of analysis corresponds to community level. Designed as a system, rainfed agriculture then includes several components or resources, including climate. With farmers of Ngayokhème rural community as the study area, the various components of the rainfed system resources have been identified. These are climate, soil, water, seeds, fertilizers, mechanical equipment, draft animals, labor, the values attached to agriculture, vegetation, and slopes. In terms of hazards, it not only undergoes the weather but is also affected by economic nature and social, cultural, institutional, political, and biophysical vagaries. So to understand the vulnerability of agriculture, it is necessary to take into account all the resources but also all types of hazards.

Given the large number of organizations and the size of the study area, we had identified four zones based on socioeconomic and ecological criteria. Each zone comprised between four and six villages and hosted two gendered focus groups. In total, eight focus groups with men and women had been organized. The practical course of these grouped interviews relied on research protocols. These consisted of matrices drawn on the flipchart and pasted on the walls of the room where the focus groups were held. Each matrix contained as many columns and rows as identified components and stressors of rainfed agricultural system. Each stressor was crossed to each component to identify the impact. To mention each impact on the flipchart, we had to find a consensual response of all members of the group. Once the components and stressors of the farming system and the impacts are identified, the following step was to proceed with the evaluation of the parameters of vulnerability.

In a second stage of building the index, the determinants of vulnerability which are exposure, sensitivity, and adaptive capacity were assessed in a participatory way. The evaluation was made based on a scale from 0 to 5 which were defined with communities. The rating scale is defined by mutual agreement between the different actors. Each scale value represents a level of each of these three parameters. Level 0 corresponds to a total lack of vulnerability. Levels 1, 2, 3, 4, and 5 correspond, respectively, to 20 %, 40 %, 60 %, 80 %, and 100 % of vulnerability. However, the evaluation was conducted with a small number of farmers (05), compared with focus groups. Indeed, as the matter is to assign numerical values to these parameters, members of the focus group should have a certain level of instruction that enables them to fully understand the meaning of each level but also the parameters of the vulnerability. They should also be active farmers that have experienced effects of climate change and be able to remember them. As we worked with the Federation of Farmers Associations, persons meeting these criteria have been provided by the Federation. Reaching consensus on the value to assign to exposure, sensitivity, and adaptive capacity of each component or resource guided the evaluation phase of the vulnerability.

Weighting of the Components

The components of the rainfed agricultural system do not have the same weight. Each component had been attributed a weight. This weighting was done by consultation with experts in the rainfed system who have accumulated extensive experience in the study area but also with the local farmers with a certain level of education allowing them to assign weights to the various components. Experts comprised agronomists (03), agricultural extension agent (01), professor (01), practitioners (01), and leaders of farmers' organizations (04). They were called at first to correct or validate the component inventory of rainfed system identified by grassroots communities in the focus groups. And secondly, they assigned a weight to each component of the system on a scale of 100. For components, some changes in terms of merging were made. Indeed, the experts asked for a definition of the content of each component. Once this is done, no significant changes in terms of addition or removal of components have been made. The values assigned by each expert were averaged to obtain the weight of each component of the system.

After attributing value to exposure, sensitivity, and adaptive capacity of each component regarding the stressors that affect them, and after pondering each component, the equation has been applied to quantify the level of vulnerability of each component and the global vulnerability of the rainfed agricultural system by multiplying each component to its weight.

Discussions

The objective of this chapter was to propose a methodological framework for building a vulnerability index to assess vulnerability of rainfed agriculture.

The analysis of various studies and vulnerability assessments revealed several gaps due to their sector or inappropriate nature. Vulnerability to climate change has been analyzed and assessed in an exclusive climate perspective or at national level. This gives an incomplete understanding of the whole impacts of climate change. Indeed, climate change does not only act directly on the elements of the natural and human systems. It also affects them indirectly through other elements. This indirect action is not always taken into account by the study and assessment of vulnerability to climate change.

The index proposed here integrates both vulnerabilities to climatic and to non-climatic shocks. In this respect, it gives the full measure of vulnerability to climate change. In fact, it takes into account the direct and indirect impacts of climate change. The construction of this index which is based on a participatory approach has shown that the qualitative and quantitative approaches can be integrated. This index and the approach that enabled to build it are applicable in different contexts because of their flexibility to adapt to different environments.

Despite these advantages of this index, it should be noted some limits. The first relates to the lack of precision that is associated with values assigned to the exposure, sensitivity, and adaptive capacity as well as components of rainfed system. Another limit refers to the fact that there is no differentiation made between farmers. The integrated index is done at community level.

Conclusion

This tool for vulnerability assessment is replicable in different contexts and accessible to all disciplines. The vulnerability of the whole rainfed agriculture as well as each of its components was quantified using a participatory approach. This tool provides a detailed framework for assessing vulnerability to climate change of rainfed agriculture, in such a manner that it can be applied by all countries in the region. Climate change is affecting rainfed agriculture in Senegal. To mitigate the impacts of climate change and increase the resilience of the sector, a robust vulnerability assessment is required. This is why an index for assessing vulnerability to climate change for rainfed agriculture has been suggested. This chapter focused on strengthening the vulnerability evidence base to support climate change policy, advancing knowledge and training to understand climate change impacts, and implementing adaptation measures. The framework presented in this chapter could yield substantial benefits for Senegal and other Sahelian countries.

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A Multi-model Framework for Climate Change Impact Assessment

Alireza Gohari, Mohammad Javad Zareian, and Saeid Eslamian

Contents

Abstract

The chapter aims to estimate the climate change impacts within a probabilistic multi-model framework. The suggested approach attempts to improve the reliability of the climate change impact assessment approach by considering the three main sources of uncertainty.

Climate change impacts on the climate variables in Iran's Zayandeh-Rud River Basin have been evaluated. Multi-model ensemble scenarios are used to deal with the uncertainty in climate change projection for the study period (2015–2044).

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The probabilistic multi-model ensemble scenarios, which include the 15 GCMs, are used to project the temperature and precipitation for the near future period (2015–2044) under 50 % risk level of climate change.

Downscaled climate variables suggest that generally temperature will rise in the Zayandeh-Rud River Basin while the level of temperature increase varies between. The maximum monthly precipitation reduction will occur in winter. This can be of considerable importance for the basin having a semiarid Mediterranean climate in which winter precipitation is the main source of renewable water supply.

In the proposed framework, the uncertainties of GCMs, emission scenarios, and climate variability of daily time series are handled by the combination of change factors and a weather generator. Covering the full range of potential climate change, such framework can provide the valuable lessons to policy maker for adapting to climate change.

The Zayandeh-Rud River Basin has been constantly facing the water stress problem during the past 60 years. The results of the climate change impacts on the basin's climate variables can provide the policy insights for regional water managers to address well the water scarcity in the near future.

Keywords
Climate change • Impact assessment • Climate variable • Zayandeh-Rud • Iran

Introduction

Climate change is a significant change in the weather conditions in long-time periods. It may be the changes in weather parameters or in the distribution of weather events (i.e., more or fewer extreme weather events). Climate change is considered as one of the major factors that will affect the water availability and life in the future (Bates et al. 2008; Eslamian et al. 2011).

Humans have been the significant contributors to greenhouse gas emissions by different industrial and household activities. The Intergovernmental Panel on Climate Change (IPCC) stated that in the Fourth Assessment Report of climate change (AR4), the air temperature increased by 0.74 °C from 1906 to 2005 (IPCC 2001).

Increased evaporation (resulting mainly from the higher temperatures), combined with regional changes in precipitation characteristics (e.g., total amount, variability, and frequency of extremes), has the potential to affect mean runoff, frequency and intensity of floods and droughts, soil moisture, and water supplies for irrigation and hydroelectric generation, which are the little effects of climate change in the recent years (Ghosh and Mujumdar 2009; Zhang et al. 2010; Eslamian et al. 2011).

Projections of climatic variables globally can be performed with General Circulation Models (GCMs), which provide the projections at large spatial scales.

These models are considered as the most credible tools for the projections of future global climate change (IPCC 2007).

An important limitation in the GCMs' application is the some sources that prevent from finality in the model outputs. These limits are often expressed as uncertainty (Moss and Schneider 2000). These include:

1. Estimating the amount of greenhouse gas and aerosol emissions is hard and has a lot of uncertainties (related to the emission scenarios) (Parry et al. 2004).
2. There are some uncertainties in GCMs (Sajjad Khan et al. 2006).
3. Global climate model sensitivities don't have the finality (Elmahdi et al. 2008).

The uncertainty in the global model configuration has long been recognized as one of the most important parts of the overall uncertainty, especially considering the first decades of the twenty-first century when the different emission scenarios do not lead to dramatically different climate responses (Benestad 2004).

To resolve these uncertainties, the different methods based on physical and mathematical relationships are presented in climate change modeling (Schaefli et al. 2007).

There are two general approaches for using of the GCMs. The first method is using a single GCM model for predicting future data (Jones and Thornton 2003; Guo et al. 2010). This may lead to an incorrect estimate of the calculated parameters in climate change models (Lee et al. 2011).

In the second method, multiple climate change scenarios are produced by the different GCMs to capture probable range of climate change impacts. This method helps to identify, better understand and more realistic modeling of the climate change (Medellin-Azuara et al. 2008; Kloster et al. 2010; Abrishamchi et al. 2012).

There are many researches in the literature for the use of multiple impact assessment models to better represent and manage these uncertainties (Tao et al. 2009; Lizumi et al. 2009; Tao and Zhang 2010; Daccache et al. 2011; Ozdogan 2011). In the recent studies, probabilistic outputs from ensembles of the GCMs models and emission scenarios have been used to achieve a better representation of uncertainties and comprehensive impact assessment. Some of them suggested that an average over the set of GCM outputs provides a dominant climate simulation related to any individual model (Bader et al. 2008; Liu et al. 2010). Elmahdi et al. (2008) have used seven AOGCMs from the IPCC third assessment report to project the future temperatures. They generated 1,000 samples of air temperature time series for uncertainty analysis and risk assessment of water demand.

This chapter aims to assess a multi-model framework for climate change impact assessment. In this framework, the uncertainties of GCMs and emission scenarios are handled by an innovated downscaling method (combination of change factors and a weather generator). The suggested approach attempts to improve the reliability of the climate change impact assessment approach by considering the three main sources of uncertainty as discussed earlier.

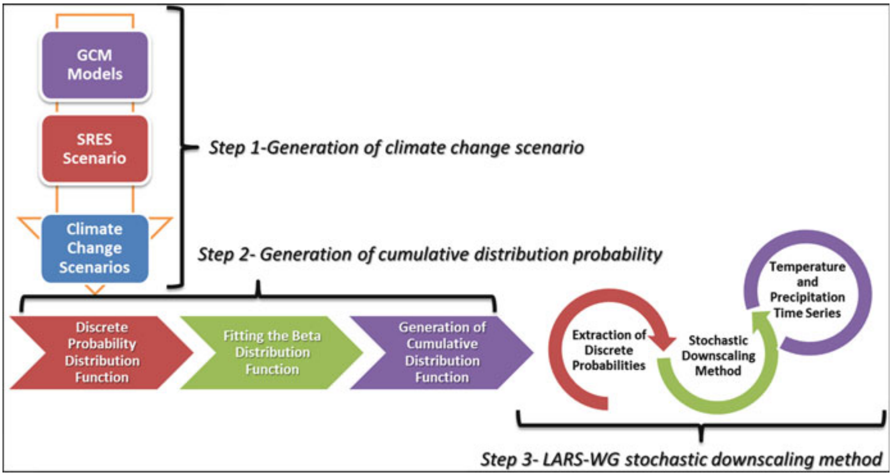

Fig. 1 Detailed flowchart of methodology

Methodology Outlines

In this study, the multi-model ensemble scenarios within the risk framework are used in order to manage uncertainty of the GCM outputs and emission scenarios. This probabilistic framework has been constructed by the combination of change factor and LARS-WG methods in the downscaling of ensemble GCMs. A detailed flowchart of this methodology has been shown in Fig. 1. According to Fig. 1, the major stages of this study consist of three steps: (a) generation of temperature and precipitation climate change scenarios by 15 GCMs for the case study, (b) generation of cumulative distribution function for climate change scenarios and extraction of climate scenarios corresponding to 50 % probabilities, and (c) generating temperature and precipitation daily time series by the LARS-WG stochastic downscaling method.

Climate Change Scenarios Generation

Generating climate change scenarios is the first step to achieve probable patterns of the future climate based on assumptions of future atmospheric concentrations. The AOGCM-derived scenarios of climate change are the most common scenario type in the impact assessments. In this chapter, 15 GCMs outputs under two emission scenarios (A2 and B1) from the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) are used (IPCC 2007). The detailed description about these models is shown in Table 1. A2 scenarios assume rapid population growth coupled with slow economic and technological development until 2100. B1 scenarios are characterized by very rapid global socioeconomic growth and population rising until 2050 and then declining toward the end of the century.

Table 1 Description about 15 GCMs from the Fourth Assessment Report (AR4) IPCC

Model	Abbreviation	Center
HadCm3	HADCM3	UKMO (UK)
ECHAM5-OM	MPEH5	MPI-M (Germany)
CSIRO-MK3.0	CSMK3	ABM (Australia)
GFDL-CM2.1	GFCM21	NOAA/GFDL (USA)
MRI-CGCM2.3.2	MRCGCM	MRI (Japan)
CCSM3	NCCCSM	NCAR (USA)
CNRM-CM3	CNCM3	CNRM (France)
MIROC3.2	MIMR	NIES (Japan)
IPSL-CM4	IPCM4	IPSL (France)
GISS-E-R	GIER	NASA/GISS (USA)
BCM 2.0	BCM	Beijing Climate Center (China)
CGCM3 T47	CGCM	Canadian Centre for Climate Modeling and Analysis
ECHO-G	ECHO	Meteorological Institute, University of Bonn Meteorological Research
INMCM 3.0	INMCM	Russian Academy of Science, Institute of Numerical Mathematics
NCARPCM	NCRPCM	National Center for Atmospheric Research (NCAR), USA

In the first step, monthly temperature and precipitation variables for the baseline period (1971–2000) and future period (2015–2044) have been extracted from the Data Distribution Center (http://www.ipcc-data.org) (DDC) of IPCC. The values of difference for the temperature and relative change for precipitation between the 30-year monthly average baseline period and future period are calculated for each month. These values represent the climate change scenarios for the temperature and precipitation's 30-year monthly averages. Here, climate change scenarios in the future period to baseline period are created separately for the different AOGCMs under two emission scenarios.

Risk Assessment of Climate Change Impacts

There are the high levels of uncertainties in the results of the AOGCM climate change scenarios. These uncertainties affect the choice of method and the confidence that can hurt the results in the impact assessment studies. There are many methods for uncertainty management, for example, expression of the results as a central prediction, central prediction with error bars, known probability distribution function, a bounded range with no known probability distribution, and a bounded range within a larger range of unknown possibilities (OECD 2003). Here, a bounded range with known probability distribution (Gohari et al. 2013a) is used for managing uncertainties due to use of ten AOGCMs, which is created from the weighting of the AOGCMs. This probabilistic multi-models approach includes the three following steps.

Weighting the AOGCMs

The ranges of monthly climate change scenarios are not the same due to different abilities of the AOGCMs to local climate simulation. So, each of the 15 GCMs used in this study separately has been weighted based on the mean observed temperature-precipitation (MOTP) method. In this method, each AOGCM has been weighted based on the difference between average of temperature and precipitation simulated by AOGCM in the base period from corresponding observed value, following the study by Massah Bavani and Morid (2005):

$$W_i = \frac{\left(1/_{\Delta}T_{ij}\right)}{\sum_{j=1}^{15}\sum_{i=1}^{N}\left(1/_{\Delta}T_{ij}\right)} \tag{1}$$

where W_i is the weight of each model in month i and ΔT_i is the temperature and precipitation change field for GCM j in month i.

Probability Distribution Function (PDF)

In this step, probability distribution function (PDF) is made, where the X and Y values represent the temperature or precipitation monthly changes and the weight of corresponding AOGCM, respectively (Fig. 2). In order to produce a time series of temperature and precipitation for the future period, the temperature and precipitation long-term monthly averages are needed. Therefore, discrete probability distributions of climate change scenarios must be converted to continuous probability distribution. Due to a high correlation and having a low number of parameters, the two parameters beta distribution function as one of the best function can be fitted on these discrete distributions:

$$\mathrm{f(x)} = \frac{\mathrm{(x-a)^{p-1}(b-x)^{q-1}}}{\mathrm{B(p,q)(b-a)^{p+q-1}}} \qquad \mathrm{a \ll x \ll b;} \quad \mathrm{p,q > 0} \tag{2}$$

where x and p and q are the variable and shape parameters for beta distribution function respectively, and B(p, q), the beta function.

The values of p and q are changed to get the best fit based on the maximum likelihood estimation method. Here, the sum of squared error (Eq. 3) is used to show how well the beta function fits the data:

$$SSE = \sum_{i=1}^{n}\left(y_i - ¥_i\right)^2 \tag{3}$$

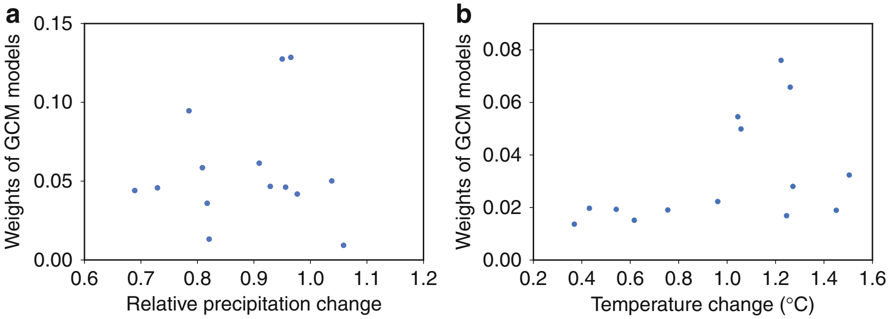

Fig. 2 Discrete PDFs, relating monthly temperature and precipitation changes to the weights of corresponding GCMs. Graph (**a**) shows the developed PDF of relative precipitation changes in May and graph (**b**) shows the developed PDF of temperature changes in February

where y_i is the data point, $¥_i$ is the estimation of beta function, and n is the number of data points ($n = 15$). The small size of sample data set can affect the goodness of fit. This is indeed a limitation of this type of assessment caused by having access to a limited number of GCMs.

Cumulative Distribution Function (CDF)

In this step, the developed PDFs are converted to CDFs. Cumulative distribution function (CDF) curve is made, where X and Y values represent the temperature or precipitation monthly changes and corresponding exceed probability (P_i). Since there is no possibility to use each point of these CDF in the impact assessment models, the monthly temperature and precipitation change scenarios have been extracted corresponding to 50 % discrete probabilities as a moderate-risk level of climate change (Fig. 3).

Stochastic Downscaling

The direct use of the AOGCM-derived climate scenarios could be impossible in impact assessment models due to large deviation of these model-derived downscale variables time series (i.e., temperature and precipitation, etc.) with real data. But long-term monthly averages of these variables are highly correlated to the real data (Semenov 2007). The downscaling techniques bridge the gap between the AOGCM outputs and required inputs by the impact assessment models (Wilby and Wigley 1997). One of the downscaling tools to generate daily climate scenarios is a stochastic weather generator (WG) (Wilks and Wilby 1985; Semenov 2007). A WG is a model, which has an ability to simulate synthetic time series of daily weather for the future by using predicted climate change scenarios from GCMs.

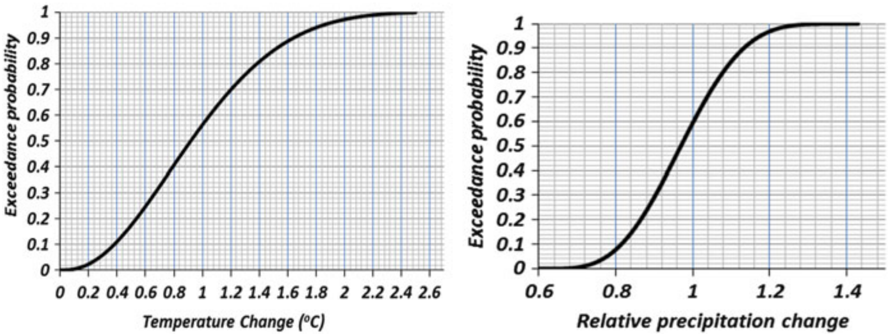

Fig. 3 Developed CDFs based on the presented PDFs in Fig. 2

LARS- Weather Generator

LARS-WG is one of the stochastic WGs that generate synthetic daily time series of minimum and maximum temperatures, precipitation, and solar radiation (Semenov 2007). The LARS-WG can generate the daily time series from monthly climate change scenarios. In the first step, the weather generator parameters calculate based on the probability distributions of locally observed daily weather variables (Semenov 2007). So, the semiempirical distributions of observed data such as frequency distributions calculate for the wet and dry series duration. Fourier series are used for describing the precipitation amount, solar radiation, and minimum and maximum temperatures. In the next step, LARS-WG generates synthetic weather data by combining a climate change scenario file for precipitation amount, wet and dry series duration, mean temperature, temperature variability and solar radiation with the resulting parameter files. In the final step, the observed data statistical characteristics are compared with those of synthetic data. A number of statistical tests (i.e., the chi-squared test, Student's t-test, and F-test) are used in this comparison to determine the differences between the distributions, mean and standard deviation values of the synthetic and observed data set (Semenov and Barrow 1997; Semenov et al. 1998).

In the present work, future daily time series of maximum and minimum temperatures and precipitation are generated for 2015–2044 based on observed daily time series and climate change scenarios for 50 % probabilities using LARS-WG. For generating 30 years daily time series, 300 years daily time series (10 × 30 years daily time series) for future period are generated by this WG and then the average daily values of these ten time series are calculated.

Case Study

The Zayandeh-Rud River Basin with an area of about 26,917 km^2 is located in central Iran (Fig. 4). In recent decades, due to high agricultural and industrial development potential, the basin has witnessed economic growth and increased

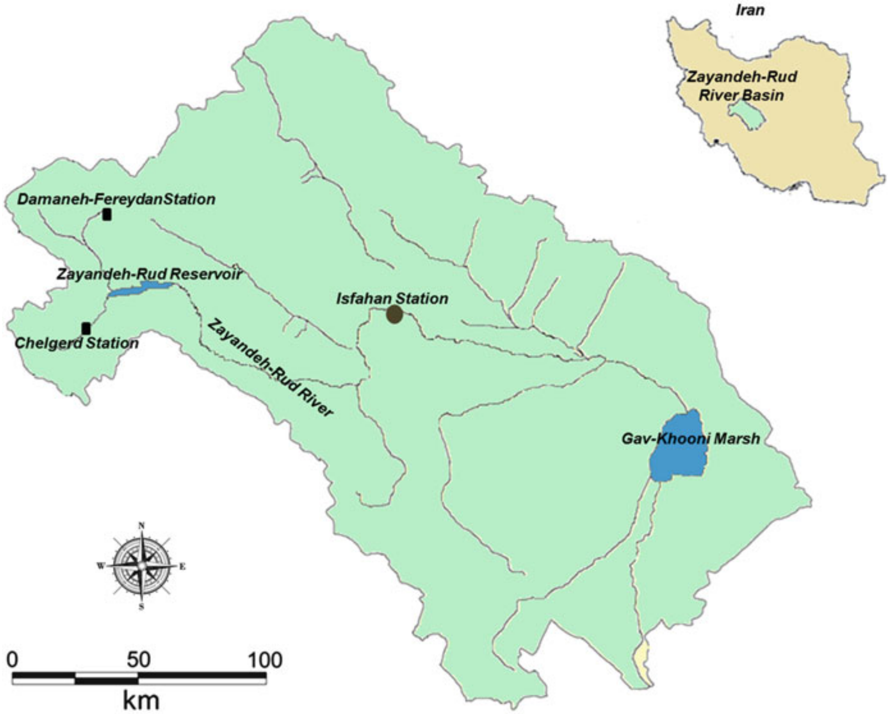

Fig. 4 Zayandeh-Rud River Basin

population (Madani and Marino 2009). Currently, more than 3.7 million people are living in the basin, making it the second most populated watershed in Iran. As the major water consumer, agriculture sector uses more than 73 % of water supply (Zayandab Consulting Engineering Co. Report 2008). Cultivation of high-water-demand crops (i.e., rice, corn, wheat, and barley) and low irrigation efficiency of 34–42 % contribute to the high agricultural water demands (Gohari et al. 2013b).

The Zayandeh-Rud River with an average flow of 1,400 million cubic meters (MCM), including 650 MCM of natural flow and 750 MCM of the transferred flow, starts from the Zagros Mountains in the west of the basin and flows into the Gav-Khooni Marsh in the east of the basin (Gohari et al. 2013b). The Gav-Khooni Marsh is recognized as an international wetland under the Ramsar Convention (1971). The river has been tapped for increasing water consumption within and outside the basin. This makes the river the most important water resource of the basin for its residents and their urban, industrial, and agricultural uses, as well as for the survival of the ecosystem of the Gav-Khooni Marsh.

Two climatological stations and a rain gauge station are selected in the study area. Table 2 presents the description of these stations.

Table 2 Brief description of the selected observation stations

Station name	Geographical position			Type of station
	Longitude	Latitude	Elevation (m)	
Damaneh-Fereydan	50° 29′	33° 01′	2,300	Climatological station
Chelgerd	50° 05′	32° 27′	2,300	Rain gauge station
Isfahan	51° 68′	32° 63′	1586	Climatological station

Impact of Climate Change on Climate Variables

Large Scale Climate Change Scenario for Temperature and Precipitation

The results of temperature changes for Isfahan synoptic station projected from ECHO-G model are presented in Table 3. Mean monthly temperature changes are generally expected to increase under climate change. Most GCMs suggest higher future temperatures in the study region while the range of expected temperature changes varies between months.

Uncertainty of Climate Change Projection

Weighting of AOGCMs

The weights of 15 GCMs for Isfahan station are shown in Table 4. The values of AOGCM weights vary between different months. The maximum weight is assigned to the CGCM3.0 model in July. The comparison of average weights of different models shows that minimum weight is assigned to the NCARPCM. The average monthly weights show that the maximum contribution of different months is related to July.

Probability Distribution Function

The discrete PDFs of climate change scenarios are developed for each month. The parameter estimation method is used to convert the discrete PDFs to continuous ones. Table 5 shows the values of SSE and beta distribution parameters for continuous temperature. The low values of SSE underline the suitability of beta distribution.

Regional Temperature and Precipitation Changes

Figures 5 and 6 respectively, show the estimated local (downscaled) temperature for Damaneh-Fereydan and Isfahan stations under climate change for various risk levels. Generally, temperature increases are expected for all months under climate change. But, the levels of increase vary between the months. The maximum

Table 3 Large-scale temperature changes for EHO-G model in Isfahan station

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2015	1.72	−0.58	3.59	2.77	1.69	2.55	1.72	2.16	1.72	2.06	2.31	1.04
2016	0.16	2.66	1.71	0.03	0.59	0.32	1.21	1.17	2.41	2.73	1.33	0.88
2017	1	0.69	0.69	1.4	1.86	3.57	2.5	1.33	1.03	1.63	2.38	1.83
2018	1.34	0.19	0.75	1.66	2.66	1.35	1.7	1.38	2.61	1.36	1.86	1.28
2019	1.26	0.95	2.5	1.3	2.46	0.5	2.5	1.44	1.27	1.96	0.82	2.5
2020	1.18	3.01	0.73	0.48	1.68	1.97	0.73	2.62	2.41	2.59	1.06	0.89
2021	2.27	1.03	0.05	2.38	1.04	0.61	0.8	1.93	0.45	2.37	1.86	1.81
2022	1.7	2.27	3.55	3.13	1.35	1.99	1.67	1.11	0.4	1.61	1.05	2.02
2023	2.32	1.51	1.36	1.57	0.72	3.23	1.43	1.75	2.89	2.44	1.52	2.7
2024	1.41	2.19	0.56	1.99	1.44	3.28	1.51	2.5	1.63	2.17	1.69	−1.08
2025	0.49	−0.97	−0.19	4.37	2.3	2.9	0.85	0.94	3.27	3.39	2.34	2.34
2026	0.09	0.19	−0.25	0	0.84	1.55	2.07	1.56	2.37	3.97	−0.59	0.27
2027	0.43	−0.05	1.14	2.49	1.78	2.03	0.72	1.5	3.88	2.91	1.12	1.68
2028	0.78	1.69	1.66	1.91	0.98	1.6	1.86	1.03	2.53	1	0.74	0.67
2029	1.33	1.94	0.21	2.53	2.03	1.9	1.56	1.84	2.85	2.02	2.72	2.78
2030	0.94	2.85	1.35	0.57	0.87	2.56	0.55	2.22	1.52	2.6	2.42	1.96
2031	1.86	2.22	1.24	2.66	1.37	2.59	2.31	1.41	2.01	1.38	1.2	0.65
2032	1.09	0.51	1.47	−0.64	1.27	3.13	2.54	2.07	0.5	3.1	2.85	3.48
2033	2.93	1.15	1.66	4.3	1.81	0.68	3.06	2.1	2.99	1.74	3.92	2.74
2034	1.8	0.1	2.35	1.98	1.41	3.05	2.52	1.69	2.59	1.76	1.66	−0.43
2035	0.92	0.59	1.45	2.79	1.6	2.55	2.46	1.96	1.15	1.79	2.63	2.45

(*continued*)

Table 3 (continued)

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2036	1.8	1.39	3.25	0.4	1.97	1.13	1.75	3.07	1.82	0.52	2.19	3.2
2037	0.46	−0.12	2.29	1.67	2.13	1.22	1.64	2.07	2.81	2.1	1.23	1.54
2038	−0.56	−0.31	1.39	2.06	1.36	2.31	1.71	2.02	2.01	1.57	3.24	0.5
2039	−0.17	1.3	−0.19	2	2.74	2.28	2.49	1.62	2.9	2.23	2.34	1.88
2040	2.18	0.74	2.28	2.36	2.35	1.14	1.29	2.59	3.13	2.76	0.96	0.72
2041	1.03	1.21	1.79	0.28	1.61	−0.1	1.5	1.61	1.3	4	4.46	1.5
2042	1.58	1.38	1.61	4.23	0.83	1.69	1.85	1.64	1.02	1.2	0.13	2.83
2043	1.69	1.51	−0.38	1.83	2.12	1.11	2.29	1.85	2.65	2.85	−0.36	1.48
2044	0.43	1.45	2.1	1.5	2.03	2.06	2.33	2.27	2.06	3.15	2.43	0.35

Table 4 Estimated weights for 15 GCMs in Isfahan station for temperature

Model	Jan	Feb	March	Apr	May	Jun	July	Aug	Spt	Oct	Nov	Dec
BCM2.0	0.017	0.020	0.025	0.035	0.008	0.025	0.004	0.020	0.015	0.007	0.027	0.019
CGCM3.0	0.022	0.029	0.032	0.037	0.011	0.109	0.896	0.154	0.033	0.012	0.031	0.019
CGCM232	0.119	0.084	0.071	0.076	0.542	0.195	0.039	0.135	0.046	0.691	0.082	0.054
CNRCM3	0.017	0.029	0.045	0.048	0.016	0.038	0.008	0.033	0.030	0.009	0.027	0.017
CSIROMK3	0.014	0.023	0.028	0.027	0.006	0.016	0.002	0.010	0.008	0.004	0.017	0.013
ECHAM5ON	0.060	0.095	0.251	0.198	0.276	0.187	0.015	0.193	0.173	0.051	0.099	0.050
ECHO-G	0.051	0.067	0.092	0.091	0.025	0.069	0.009	0.055	0.071	0.067	0.133	0.066
GFDL21	0.022	0.031	0.030	0.029	0.007	0.025	0.004	0.020	0.015	0.007	0.023	0.019
GISS-ER	0.396	0.232	0.145	0.066	0.026	0.183	0.003	0.014	0.018	0.068	0.051	0.076
HADCM3	0.026	0.032	0.031	0.029	0.006	0.016	0.002	0.013	0.010	0.006	0.024	0.022
INMCM3.0	0.077	0.079	0.059	0.045	0.009	0.015	0.001	0.009	0.009	0.006	0.033	0.032
IPSLCM4	0.043	0.054	0.059	0.062	0.018	0.046	0.010	0.293	0.532	0.044	0.109	0.060
MICRO3.2	0.090	0.171	0.075	0.187	0.027	0.029	0.002	0.011	0.012	0.015	0.294	0.511
NCARCCSM3	0.029	0.033	0.035	0.042	0.016	0.034	0.004	0.031	0.019	0.009	0.032	0.028
NCARPCM	0.015	0.021	0.022	0.026	0.006	0.013	0.001	0.009	0.009	0.005	0.019	0.015

Table 5 The estimated values for beta distribution parameters in Isfahan station (temperature)

Month	α	β	a	B	SSE
Jan	5.00	6.00	0.54	1.52	0.01
Feb	5.78	5.00	0.30	1.49	0.01
March	6.36	4.00	0.19	1.33	0.00
Apr	4.13	6.00	0.22	2.35	0.00
May	5.00	4.88	0.11	1.95	0.00
Jun	5.00	4.00	0.44	1.73	0.01
July	3.24	6.00	0.05	3.01	0.02
Aug	6.00	3.85	0.09	1.75	0.03
Sept	3.00	5.00	0.25	2.50	0.02
Oct	5.83	4.78	0.41	1.43	0.01
Nov	3.91	6.00	0.37	1.75	0.01
Dec	2.56	7.00	0.53	2.48	0.01

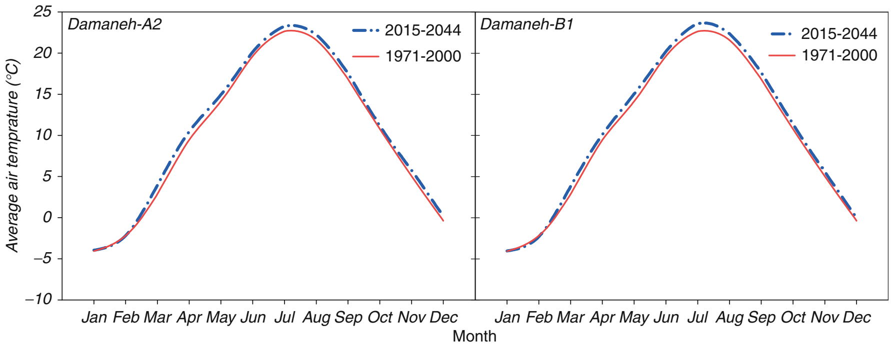

Fig. 5 Comparison of the baseline (1971–2000) and future (2015–2044) period 30-year average temperature under A2 and B1 emission scenarios in Damaneh-Fereydan station

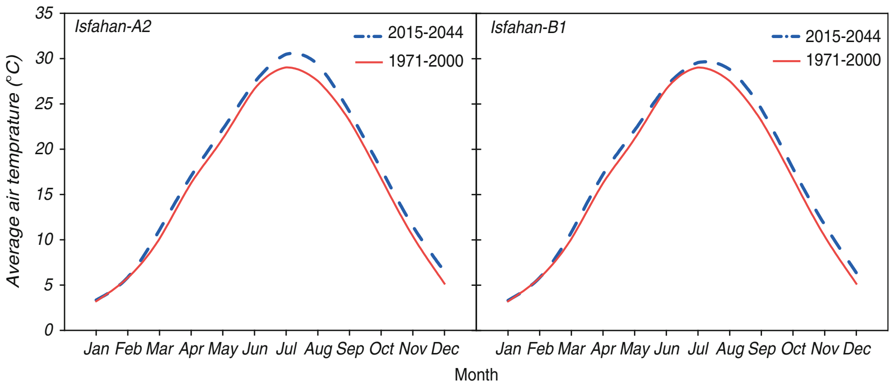

Fig. 6 Comparison of the baseline (1971–2000) and future (2015–2044) period 30-year average temperature under A2 and B1 emission scenarios in Isfahan station

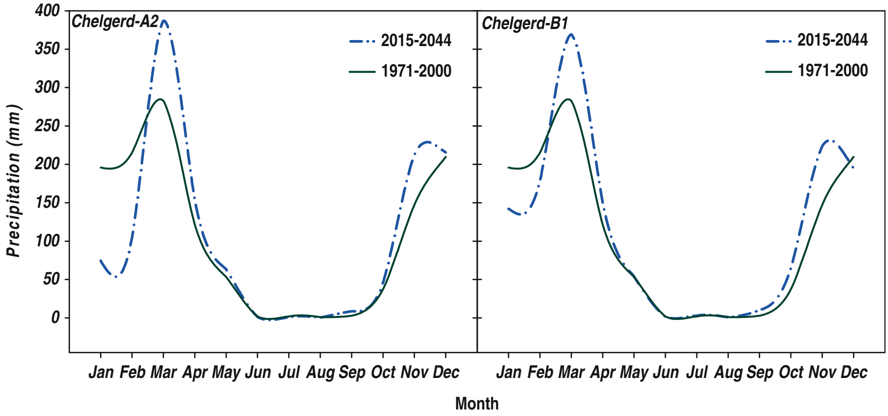

Fig. 7 Comparison of the baseline (1971–2000) and future (2015–2044) period 30-year mean monthly precipitation under A2 and B1 emission scenarios in Chelgerd station

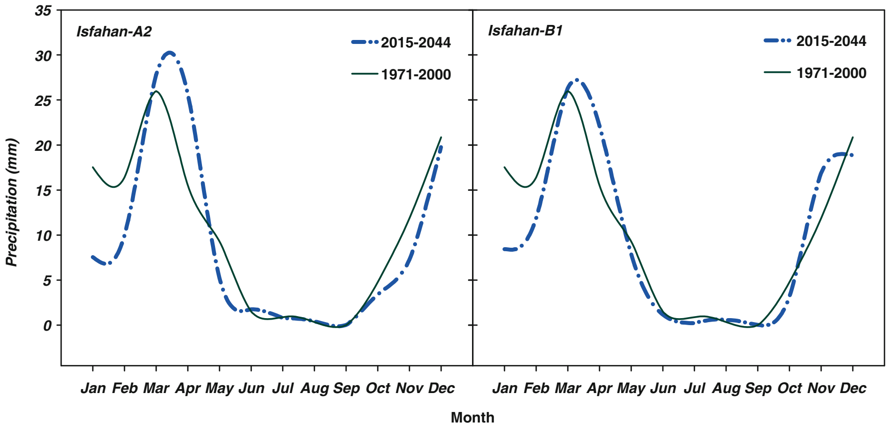

Fig. 8 Comparison of the baseline (1971–2000) and future (2015–2044) period 30-year monthly mean precipitation under A2 and B1 emission scenarios in Isfahan station

temperature changes in Damaneh-Fereydan are expected in spring and summer months, respectively, under A2 and B1, while maximum temperature change fields in Isfahan station are simulated in summer and fall months, respectively, under A2 and B1.

Unlike the results for temperature, the local precipitation changes do not show a general increasing trend (Figs. 7 and 8). The results show that the maximum monthly precipitation decreases in Isfahan and Chelgerd stations in January under A2 and B1.

The projected annual and seasonal changes of 30-year mean temperature and total precipitation were calculated under A2 and B1 (Tables 6 and 7).

Table 6 Temperature changes (°C) in the study area under different emission scenarios

	Isfahan		Damaneh-Fereydan	
Month	A2	B1	A2	B1
Jan	0.13	0.10	0.10	0.03
Feb	0.05	0.02	0.00	−0.11
Mar	0.95	0.71	1.05	0.91
Apr	0.77	0.95	1.00	0.65
May	1.03	0.93	0.78	0.89
Jun	0.70	0.31	0.46	0.53
Jul	1.45	0.54	0.61	0.94
Aug	1.81	1.27	0.62	0.75
Sep	1.01	1.34	0.69	0.82
Oct	1.05	1.11	0.39	0.62
Nov	1.12	1.28	0.72	0.55
Dec	1.31	1.22	0.55	0.36
Max	1.81	1.34	1.05	0.94
Min	0.05	0.02	0.00	−0.11
Mean	0.95	0.82	0.58	0.58
Winter	0.38	0.28	0.38	0.28
Spring	0.83	0.73	0.75	0.69
Summer	1.42	1.05	0.64	0.84
Fall	1.16	1.20	0.55	0.51

Table 7 Precipitation changes (%) in the study area under different emission scenarios

	Isfahan		Chelgerd	
Month	A2	B1	A2	B1
Jan	−0.57	−0.52	−0.62	−0.27
Feb	−0.39	−0.28	−0.52	−0.17
Mar	0.07	0.01	0.37	0.31
Apr	0.66	0.43	0.27	0.24
May	−0.44	−0.15	0.19	0.01
Oct	−0.29	−0.34	0.23	0.63
Nov	−0.39	0.42	0.44	0.52
Dec	−0.05	−0.10	0.03	−0.07
Max	0.66	0.43	0.44	0.63
Min	−0.57	−0.52	−0.62	−0.27
Mean	−0.17	−0.06	0.05	0.15
Winter	−0.30	−0.26	−0.26	−0.05
Spring	0.11	0.14	0.23	0.13
Fall	−0.24	0.00	0.23	0.36

With 5–15 % decrease in Chelgerd's precipitation and 0.58 °C increase in Damaneh-Fereydan's temperature at annual scale, the upper subbasin will face warmer and drier conditions under climate change. The results of Isfahan station indicate that the lower sub-basin will experience warmer (0.82–0.95 °C) and dryer (6–17 % reduction in precipitation) conditions than the upper subbasin in the future.

Conclusions

In this study, 15 GCMs are used under two emission scenarios to estimate climate change impacts on climate variables in the Zayandeh-Rud River Basin. To deal with the high uncertainty in the estimated temperature and precipitation changes under climate change, the weighted ensembles of GCMs' outputs were generated and climate change variables at 50 % risk levels (a medium-risk level) were estimated. The results suggest that generally temperature will rise in the study area while the level of temperature's increase varies between the months. Monthly precipitation changes do not show a general increasing or decreasing trend.

Upper subbasin precipitation especially in winter is known as the main resource of surface water in the Zayandeh-Rud River Basin. The results indicate that maximum monthly precipitation reduction (5–26 %) will occur in winter and annual precipitation is expected to decrease by 5–15 %. This can be of a considerable importance for the Zayandeh-Rud River Basin with semiarid Mediterranean climate in which winter precipitation is the main source of renewable water supply. Temperature rise will lead to more precipitation falling as rain, instead of snow, and the snowpack will melt earlier in the spring. The reduced snowfall due to increasing temperature in winter months will generally lead to more severe water shortages in such arid and semiarid regions under climate changes.

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A Socio-Economic Evaluation of Community-based Adaptation: A Case Study in Dakoro, Niger

Olivier Vardakoulias and Natalie Nicholles

Contents

Abstract

Community-based adaptation (CBA) is gaining popularity as an approach to supporting vulnerable communities to adapt to the impacts of climate change, but in an environment of competing financial demands, to what extent is CBA economically efficient?

Empirical research from NEF Consulting (New Economics Foundation) using an extended social cost-benefit analysis (SCBA) of qualitative and quantitative data gathered from four communities compares and contrasts the benefits and

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investment in CBA initiatives carried out by the Adaptation Learning Programme (ALP), implemented by CARE International in Dakoro, Niger.

The results suggest a high return on investment on ALP's CBA activities in Dakoro and an increase in the economic capital of communities (revenue and savings) as well as social and environmental capitals. Even only taking into account the benefits ALP has generated to date (over 4 years), findings suggest that for every £1 invested in communities, there has been a return of more than £4. In order to capture the future value of community-based adaptation, the evaluative model was extended further to forecast evolutions to 2020 using three core climate scenarios to evaluate the impact on the different forms of communities' capital under a no intervention scenario, compared to an intervention scenario. Even under a high discount rate, results remain positive and returns are high, proving that CBA is both an economic and socially effective approach to adaptation.

Keywords
Climate change • Community-based adaptation • Social cost-benefit analysis

Introduction

Climate change is one of the greatest threats facing poor and marginalized communities (Parry et al. 2007). As the possibility of keeping global temperature increase to 2 °C looks increasingly unlikely under current projections (IPCC 2013), societies will be faced with the challenge of adapting to the imminent impacts of climate change. The impacts of climate change will exacerbate existing challenges such as economic crises, natural disasters, environmental degradation, and conflict (Buhaug et al. 2008). This poses new challenges for development practitioners, policy-makers, and national and local governments, who will increasingly need to take into account future impacts of climate change. This will require building resilience and capabilities within communities to respond to the impact of climate change. With this in mind, new research conducted by NEF Consulting (New Economics Foundation) sought to answer the question of which adaptation strategies are the most effective and would therefore benefit from most investment.

Community-based adaptation (CBA) has been growing in popularity as an approach to supporting communities to adapt to the impacts of climate change (IIED 2009). The key aspects of the approach are a focus on both "hard" and "soft" adaptation strategies, the importance of action at all levels (community, regional, and national), embedding adaptation practices and actions into community life by codesigning approaches to adaptation, and stressing the importance of both quick win activities (such as disaster risk reduction measures) as well as building longer-term adaptive capacity (Ensor and Berger 2008). In short, CBA provides an effective, practical, and integrated approach which strengthens adaptive capacity and supports planning and implementation of DRR and climate-resilient development, informed by knowledge of climate information and risks. It seeks to address broader underlying causes of vulnerability which, if left unchallenged, would prevent the achievement of resilient outcomes (Ensor and Berger 2008).

There are a range of research methods which are suitable for testing the efficiency and effectiveness of adaptation strategies promoted as part of CBA, including both quantitative and qualitative methods (GIZ 2013). Social cost-benefit analysis (SCBA), including its variants like social return on investment (SROI), is widely regarded as one of the most appropriate methods for assessing effectiveness and efficiency from a socioeconomic perspective. By comparing the wider benefits (economic, social, and environmental) generated by an intervention against the costs, SCBA determines whether available resources are used in an efficient and effective way (Dreze and Stern 1987). This enables an analysis of which strategies are most effective in delivering intended change when compared against others.

This chapter presents the research conducted by NEF Consulting using a SCBA approach to evaluate and appraise the adaptation strategies promoted as part of the CBA approach by the Adaptation Learning Programme for Africa (ALP), implemented by CARE International in Niger. CARE International launched ALP in 2010 with the aim of identifying the problems faced by communities in the context of climate change, determining potential current and future solutions both for communities and the wider region, and building a robust community-based adaptation approach, which takes into account broader macro-institutional conditions and strategies, both regional and national. The ALP is carried out in four countries in Africa – Kenya, Niger, Mozambique, and Ghana. The program aims to generate learning on community-based adaptation to climate change in order to inform best practice for adaptation and development practitioners as well as local, national, and regional policy- and decision-makers (Fig. 1).

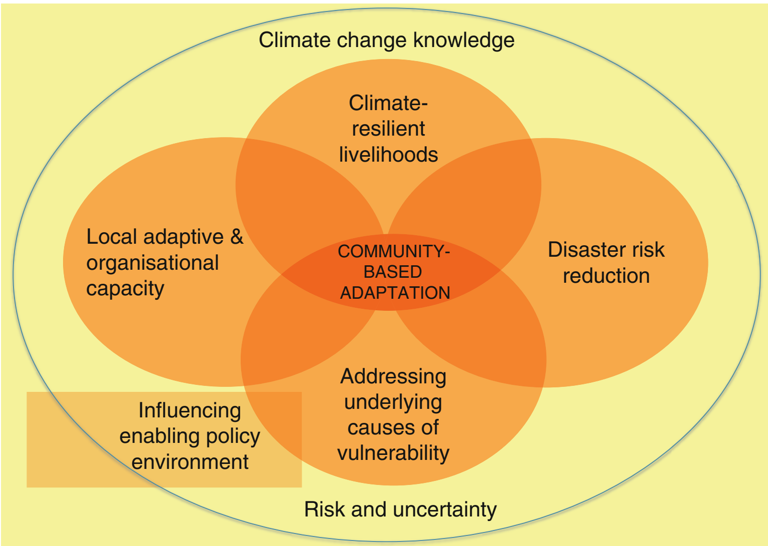


Fig. 1 Scope of Adaptation Learning Programme

Purpose of the Evaluation

In 2011, NEF Consulting carried out a socioeconomic analysis of community-based adaptation interventions carried out by ALP in Kenya. This created much interest and discussion in the efficiency and effectiveness of investing in community-based adaptation (Nicholles and Vardakoulias 2012) although the methodology used remained entirely forecastive. It was therefore agreed that a follow-up study using an evaluative approach to analyze ALP was needed to deepen understanding in this area. ALP started work in Niger in 2010 which meant that it was a good location for the study due to the longevity of the project. The objectives for the research were as follows:

- To use extended cost-benefit analysis methodology to conduct a socioeconomic analysis of community-based adaptation
- To analyze the results against the "broader" picture, i.e., comparing community based to no adaptation and/or to other development interventions that do not take adaptation into account

In addition to this, the assignment aimed to simplify the original cost-benefit model used in Kenya so that the approach, learning, and results could be used by ALP and local government stakeholders to make decisions about the allocation of funds for activities which support climate change adaptation.

Climate Change in Niger

Niger is one of the most vulnerable countries in the world and is highly dependent on climate conditions due to the nature of its geographical location and socioeconomic characteristics (Republique du Niger 2006). Niger's economy and the livelihoods of its population are highly sensitive to the impact of climate changes due to 40 % of its GDP being based on agriculture and 80 % of the population being dependant on agriculture for their livelihoods (World Bank 2013).

Over the years Niger has been consistently affected by droughts which are one of the drivers of vulnerability in terms of food crises, with no less than seven severe droughts since 1980 (World Bank 2013). This has resulted in successively undermining agricultural and livestock production on which most of the population depend. This is exacerbated by a number of other factors and risks including recurrent locust outbreaks, floods, desertification, land degradation, and poor resources and infrastructure to deal with these shocks. Figure 2 presents the economic impacts of these shocks from 1980 to 2010.

Climate vulnerability is therefore just one of many interrelated pressures – climatic, socioeconomic, institutional, and ecological – that Niger's agricultural sector experiences (World Food Programme 2010). It is also important to note that while agricultural production has increased as shown in Fig. 2, production per capita has been decreasing since the 1960s (Ozer 2007). Therefore, agricultural

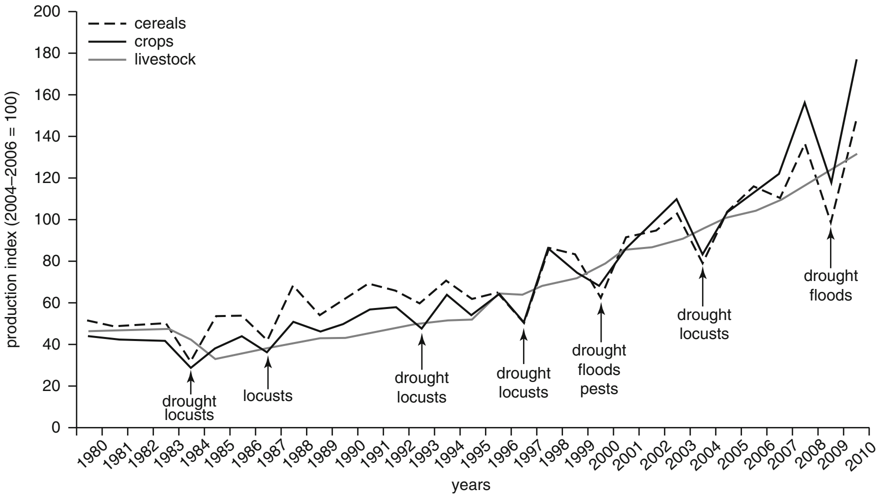


Fig. 2 Impacts of shocks on agricultural and livestock production in Niger (1980–2010)

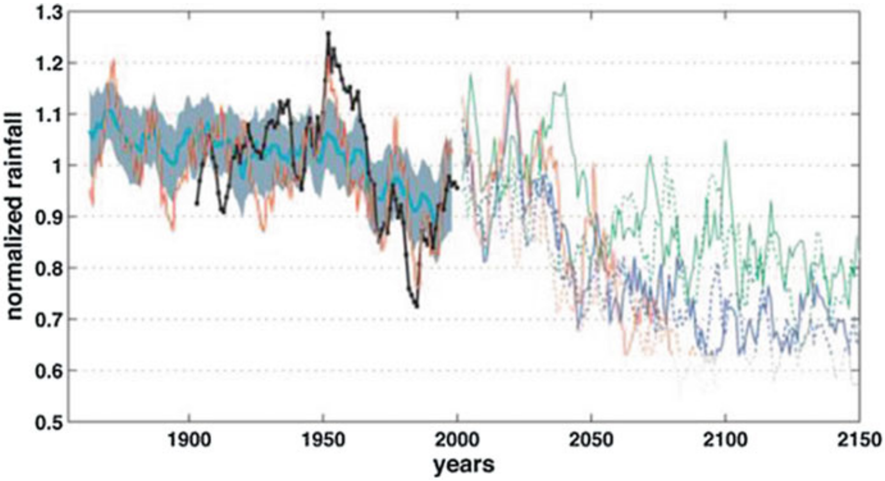


Fig. 3 Historical and projected rainfall patterns in the Sahel

production is not keeping up with population increase, which means that an increasing number of households are at risk of malnutrition.

In the Sahelian zone, there is broad agreement that there is a decreasing trend in rainfall since the mid-twentieth century (Held et al. 2005). However, after a dry period lasting until the 1980s, rainfall has been increasing ever since. It is important however that these average conditions do not hide the increase in extreme rainfall events, anomalies in rainy seasons, and the fact that due to the chaotic nature of the climate system, the current wetter period might not last. In fact some downscaled global models predict that there will be a slow but sure decrease in rainfall across the Sahel rather than an increase as well as changes in the seasonality of precipitations (Held et al. 2005; Yayé et al. 2013; Fig. 3).

Even if, as some downscaled models predict, overall precipitation will slightly increase or remain stable, all models agree on significant increases in mean temperature for the region. The impact of this increase in mean temperature on soil fertility and moisture is unlikely to be balanced out by the increase in precipitation. Furthermore, most models forecast a decrease in the length of growing period (LGP) and therefore a decrease in agricultural production as a consequence of temperature increase (Yayé et al. 2013). Looking at the overall picture, the climate projections for the Sahel region, coupled with population growth, are likely to increase existing vulnerability in Niger (Fig. 4).

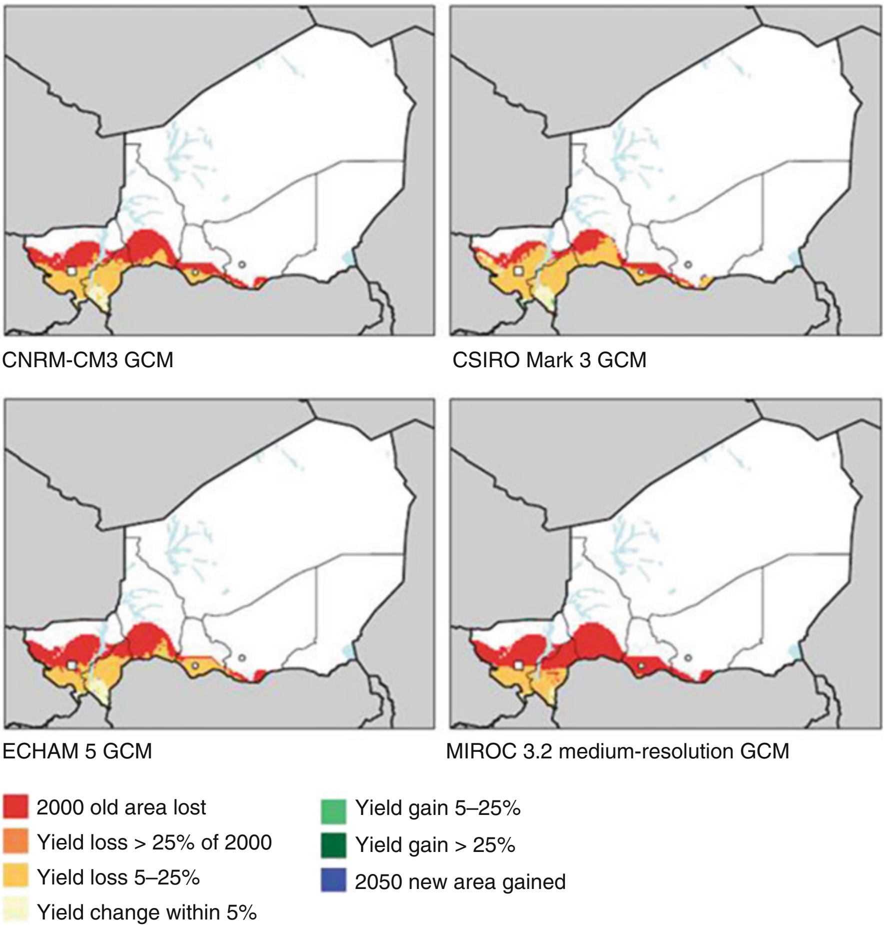
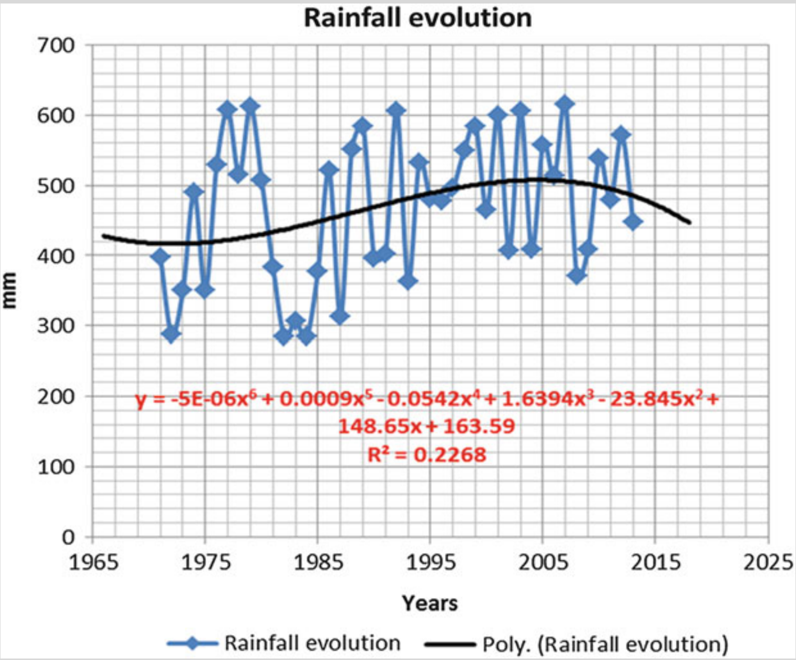


Fig. 4 Projected yields of rain-fed sorghum under different precipitation and temperature scenarios

The department of Dakoro, where the ALP is operational, experiences precipitation anomalies typical of the Sahelian zone. The study was unable to find climate model forecasting for the region of Dakoro, but by looking at past historical records, it is clear to see just how vulnerable the region is. The province has been hit by six severe or catastrophic droughts between 1981 and 2000, this is equivalent to one severe or catastrophic drought happening every 4.8 years (World Bank 2013). The study took raw data from the weather station in Maradi (120 km south of Dakoro) and analyzed it revealing that precipitation patterns in the region are chaotic, demonstrating high vulnerability on a year-on-year basis (INS Niger 2010) (see Box 1). This presents a major challenge for rural communities who are dependent on rain-fed agriculture, as demonstrated by the economic analysis conducted by the World Bank which suggests that output of major crops is correlated to rainfall by a factor of 0.60 (World Bank 2013).

Box 1: Rainfall Evolution in the Region of Maradi (1965–2013)



The sample communities which are the focus of this research are therefore situated in a particularly vulnerable environment where the predominant form of agriculture is rain-fed and water resources are limited – particularly during the dry season of October to May.

Methodology: Understanding Change and Impact

This study takes a socioeconomic perspective of community-based adaption, which is not only useful in understanding the impact of CBA but also provides an effective framework for evaluation.

The three factors are interrelated; if people have enough access to resources and also have the skills and knowledge to use them in the most effective way possible, then they are less likely to need or deplete their resources when a shock occurs. It is this assumption that is tested in this evaluation (Fig. 5).

Following on from the study which was conducted in Kenya in 2011, this research combines a traditional cost-benefit analysis approach with the underlying principles of SROI (Lawlor et al. 2008). This results in a three-pronged approach to the methodology:

- Developing theories of change (ToC) through engagement with primary stakeholders and the ALP team
- Measuring quantitative social and economic capital evolutions using empirical research with primary stakeholders
- Assessing quantitative environmental capital evolutions and climate variability through extensive literature reviews and secondary desk-based research in order to fill gaps identified in empirical analysis

The evaluation is composed of two main components, modeling the resilience of communities to shocks relative to a business-as-usual scenario and then modeling how this resilience impacts on the long-term prospects of communities – relative to a business-as-usual scenario. In short, the evaluation analyzes the value created by ALP's interventions in economic, social, and environmental capital in comparison to investment.

ALP works in 20 communities across four communes in Dakoro; therefore, the study was undertaken in a representative sample of communities chosen for the ALP.

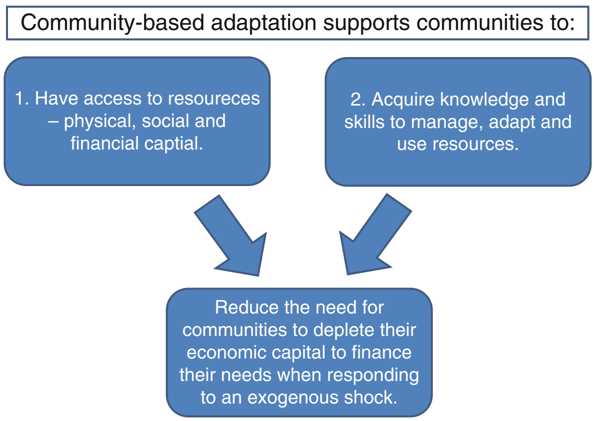


Fig. 5 ALP's framework for community-based adaptation

Table 1 Sample construction based on level of vulnerability

	Total households	D = extremely vulnerable	C = very vulnerable	B = vulnerable	A = moderately vulnerable	Total
Maiwassa	230	6	5	1	1	13
Dan Ijaw	124	1	4	2	1	8
Kouggou	49	0	1	2	1	4
Gomozo	81	2	2	1	1	6
Total	484	9	12	6	4	**31**

The communities chosen for the sample were Maiwassa, Dan Ijaw, Gomozo, and Kouggou. This was based on three key selection criteria, ethnic group, level of vulnerability, and proximity to the Tarka valley, as these factors are considered to have the most impact on the effectiveness of community-based adaptation. There are three main ethnic groups in the communities, Hausa, Fulani, and Toureg, with Hausa being the dominant group among the 20 communities. In order to ensure this distribution, two Hausa, one Fulani, and one Toureg community were selected. It was decided that the most feasible sample size would be 5 % of households within the communities, broken down by vulnerability levels.

The levels of vulnerability were defined by taking into account household income and assets, and the vulnerability categories were defined by communities themselves. Communities were asked to collectively determine and identify which households were to be classified as "extremely vulnerable" through to "moderately vulnerable" based on a number of criteria including amount of assets (land, livestock, tools, etc), agricultural production output, social position within the community, quality of housing, and nutritional coverage.

Vulnerability was assessed and weighted across the levels, this was to account for the fact that in some cases, 5 % resulted in less than a whole household (see Table 1).

Theory of Change

Qualitative data on how the four communities selected for this research experienced the impacts of climate change prior to the start of ALP in 2010 and in 2013 when this research was conducted was collected via stakeholder engagement. Communities were asked to retell their stories across a range of parameters including social and economic impacts. A counterfactual scenario was also explored to find out how communities felt they would have experienced climate change in the absence of ALP. This can be illustrated through a theory of change diagram which presents the need for ALP as expressed by the challenges induced by climate change (Fig. 6).

The *prevailing conditions* are the reasons why ALP intervenes in the communities because collectively they increase vulnerability to a climate shock. When a climate shock does occur, this often results in weakened economic capital (crop failure or weak livestock), and a vicious cycle of not being able to plan and develop strategies

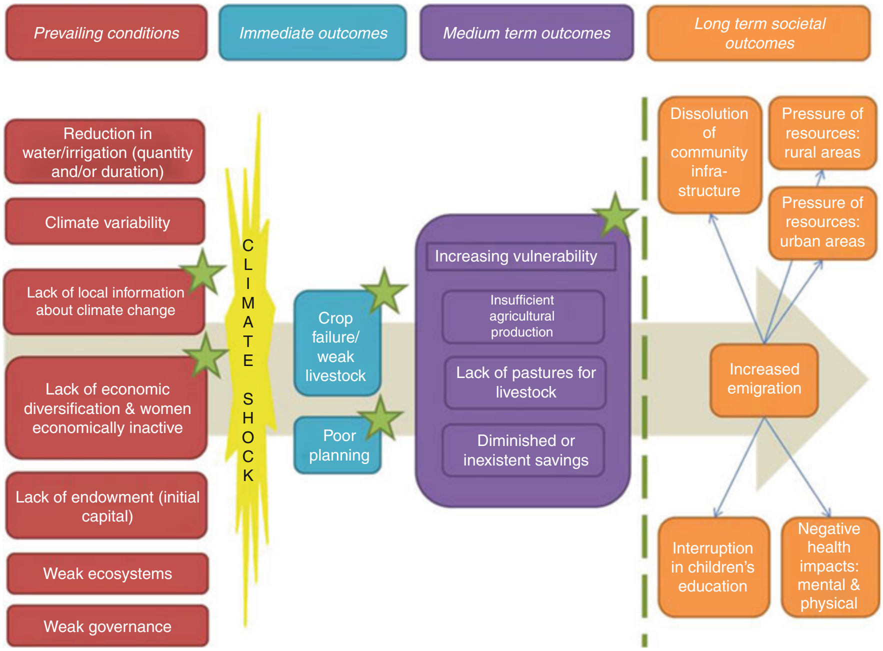


Fig. 6 Theory of change for business as usual

for forthcoming shocks ensues. These, alongside the prevailing conditions, increase communities' vulnerability from an economic perspective.

According to the communities, one of the longer-term impacts of increased vulnerability is rural to urban and peri-urban migration which can lead to a number of impacts including breakdown in community infrastructure, increased resource pressure on both urban and rural areas, interruption in children's education, and a detrimental impact on both physical and mental health.

ALP has clear strategies to prevent these longer-term outcomes from occurring: to increase communities' resilience to the uncertainty and impacts of climate change. Denoted by the green stars in Fig. 6, ALP intervenes to address the lack of local information about climate change, the lack of economic diversification, and women's economic role within communities. It then works to address weakened economic capital and poor planning, which is about focusing on the core needs of the community to build their resilience. This is where ALP is aiming to influence, as denoted by the line of accountability. The line of accountability is a tool that allows for understanding of ALP's sphere of influence and for better measurement of impact.

Once communities articulated the need for ALP's intervention, they then shared the social, economic, and environmental outcomes they had seen following the adoption and integration of adaptation strategies. Figure 7 presents the theory of change as captured through the stakeholder engagement.

ALP supports the process of action planning for community-based adaptation, which enables communities to decide on relevant and locally appropriate adaptation

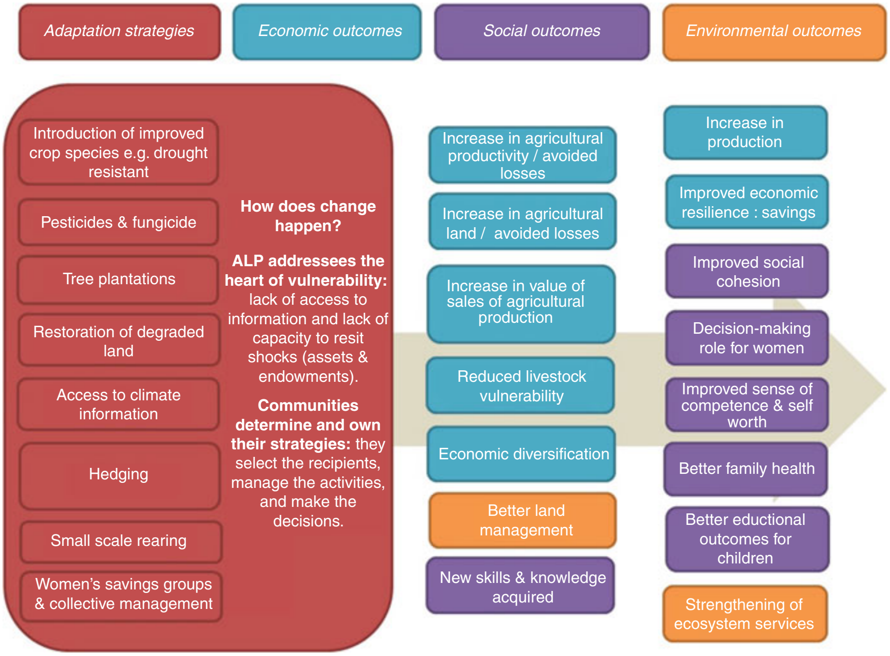


Fig. 7 Theory of change for community-based adaptation

strategies. Each community applies a mixture of adaptation strategies selected by them. Indeed, this point is crucial to understanding the theory of change: communities determine their own strategies, select the recipients, and make the decisions about who is responsible and how resources are allocated. These decision-making processes are informed by climate vulnerability and capacity analysis, and climate information in some form. Adaptation strategies are multiple and usually involve activities related to livelihoods, risk reduction, or advocacy initiatives. These aim to reduce vulnerability and risk and result in climate-resilient and more equitable livelihoods, which are adapted over time. Example strategies range from improving crops (such as drought-resistant crops), community-based hedging mechanisms (known as warranting), small-scale rearing (one or two goats), and women's collective savings structures.

The qualitative information to create the theories of change provided a guide for which hypotheses needed to be tested and evidenced through quantitative data collection. These hypotheses are that:

- Economic capital improves through increasing production (either agricultural productivity or land; increasing the value of sales or reducing livestock vulnerability), economic diversification (mostly where women undertake economic activities), and improving savings. All contribute to greater resilience from an economic perspective.
- Social capital improves through learning new skills and acquiring knowledge and making collective decisions. Communities reported having better relationships

and a sense of cohesion, improved sense of self-worth as a result of feeling more in control of their future, and better general educational and health outcomes for families and children. The decision-making role of women changed through ALP's work, as many of the strategies are run by women, and they reported enjoying their newfound role within their families. Interestingly, while the men showed support for the women's active participation and management of economic resources, women's increased independence (such as allowing women to go to the market) was not experienced in the same way across all the communities.
- Environmental capital improves through strategies that encourage better land management and the strengthening of ecosystem services. Tree plantations and the restoration of degraded land support the maintenance of critical ecosystem services in fragile ecosystems of the Sahel.

The hypothesis is equally that these three forms of capital interact in various ways. An improvement of ecosystem services, for example, underpins the economic sustainability of communities by preventing land degradation, which could reduce incomes from agriculture. Similarly, economic capital impacts on social capital, for instance, by preventing the breakdown of communities and/or emigration of youngsters from the communities. Finally, institutional empowerment can be a critical economic driver, by ensuring that communities are able to adapt and build resilience strategies in the future.

Environmental, Economic, and Social Outcomes

The research used a questionnaire to measure the quantitative change in economic, social, and environmental variables. The aim was to see whether the interventions carried out by ALP have affected broad economic, social, and environmental outcomes. These include communities' income from agricultural activities, education, health, social capital, and the key ecosystems on which communities rely. This required data collection which evidenced change in adaptive capacity and change in typical development outcomes. Change was measured using a retrospective approach to assess the level of capital before the start of the ALP (2009) to provide a baseline and then post intervention in 2013. This approach gives a measurement of "gross" change, in other words a level of change which does not take into account the counterfactual (what would have happened anyway) or the attribution of other actors/factors in influencing this change. Below is a summary of the key results for each type of capital.

Key Economic Outcomes

The communities in which ALP works in Niger are highly dependent on agriculture and livestock for their livelihoods as described earlier. The economic data collected therefore focused on the evolution of agricultural and livestock returns since the beginning of the ALP. In addition to this, savings and degree of diversification were also assessed.

The data collected in relation to agricultural activities shows three main findings: there has been an increase in productivity of all major crops, there has been an extension of agricultural productivity, and there has been an increase in agricultural revenue since the start of the program. Sorghum was the only major crop where a decrease in productivity was experienced, but it is difficult to ascertain why this might be. One possible reason might be that the increase in agricultural land might represent an extension into more marginal (less productive) land which can have an influence on overall productivity. Furthermore this slight decrease must be considered alongside a business-as-usual scenario (see section on additionally) (Figs. 8 and 9).

In addition to this, there has been an increase in agricultural returns across all crops during the same period, as represented in Fig. 10. It is important to note that

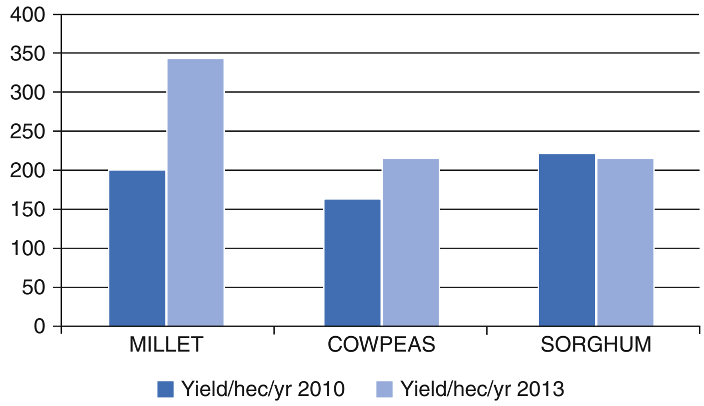


Fig. 8 Evolution of agricultural productivity (kg/ha/year)

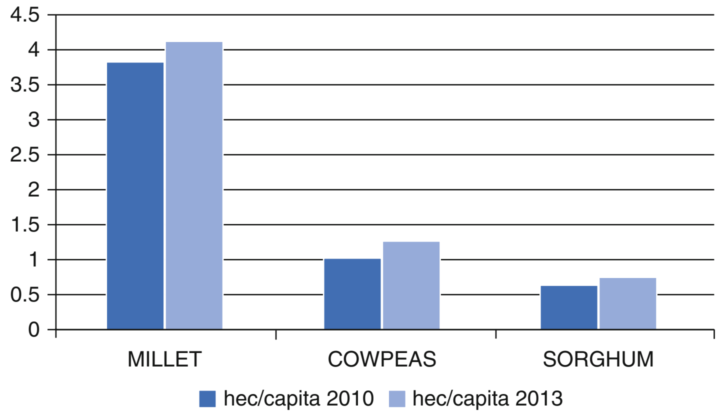


Fig. 9 Evolution of land tenancy

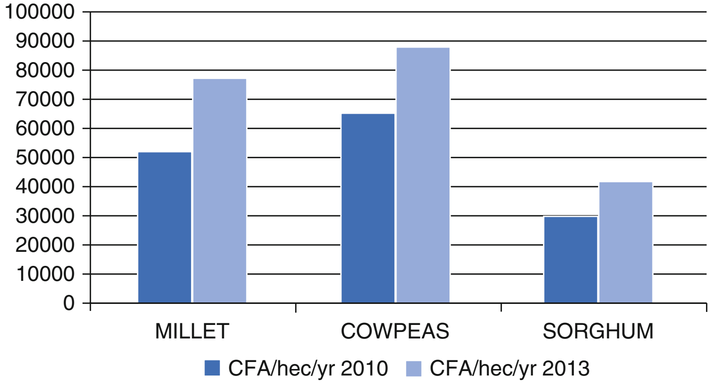


Fig. 10 Average returns per hectare

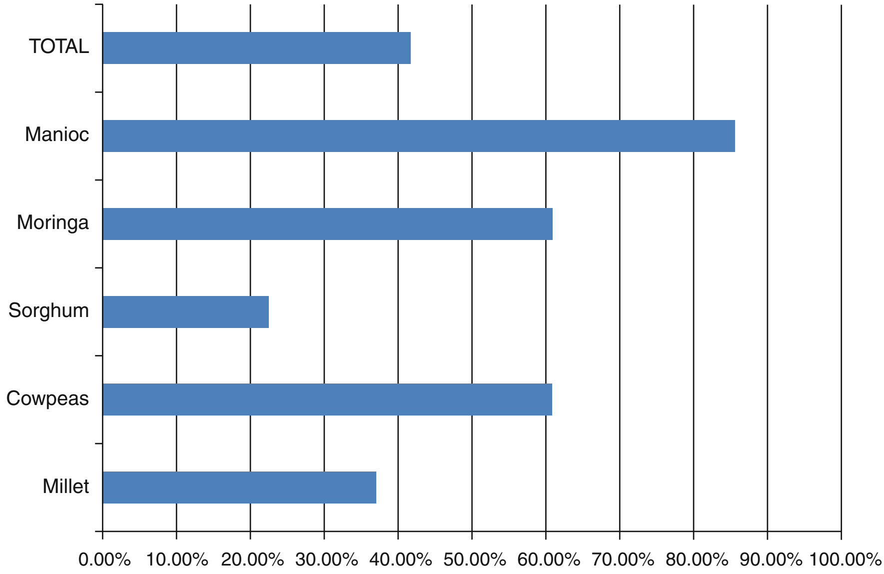


Fig. 11 Change in net revenue from crops

agricultural returns are different to agricultural yields. One of the reasons why agricultural yields per hectare may have increased more than actual agricultural productivity could be due to the impact of the warrantage system in Niger, an adaptation strategy which involves storing excess produce at the end of the rainy season and selling it on the market when prices are higher although this theory would need to be tested.

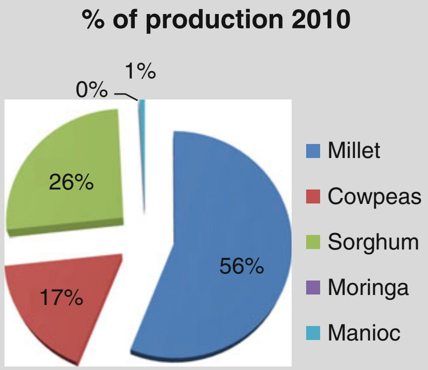
The combination of intensification, extensification, and warranting has resulted in a 41.8 % average increase in agricultural revenue between 2009 and 2013, as shown in Fig. 11. This figure is net of debt repayment and costs of production inputs.

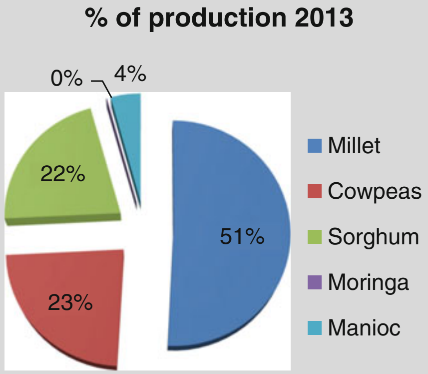
Crop diversification is another factor which has an impact on economic assets and therefore should be considered alongside intensification and extensification. Based on the data collected, only a very modest diversification of crops has taken place in the communities during the period under investigation (2009–2013), as presented in Box 2.

The development of livestock activities is a more complicated picture. While there seems to have been a slight decrease in total ownership of livestock – as determined by headcounts of cattle, goat, sheep, donkeys, camels, and poultry (see Fig. 12) – the total value of and revenue derived from livestock and poultry have increased (see Box 3).

Furthermore, a decrease in livestock headcounts can also be indicative of communities placing more emphasis on and investing more resources in agriculture. The two hypotheses are not mutually exclusive.

Box 2: Structure of Agricultural Production





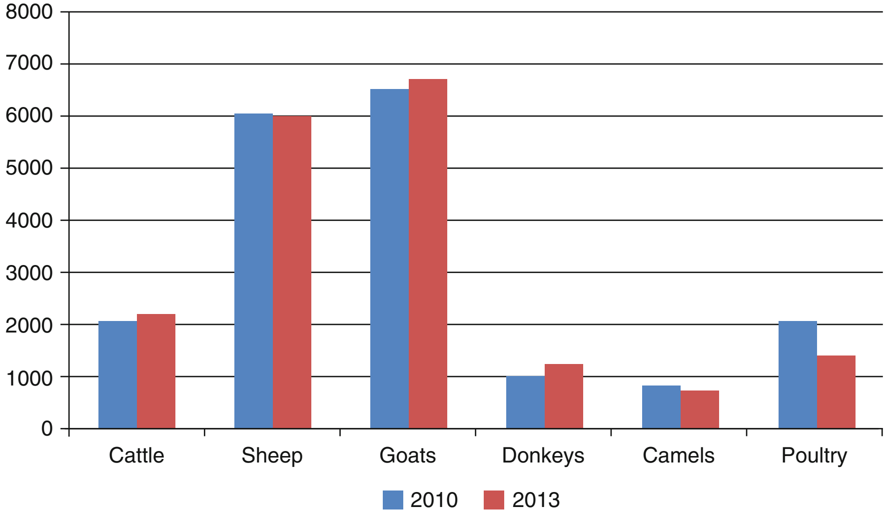


Fig. 12 Total livestock and poultry expressed in headcounts

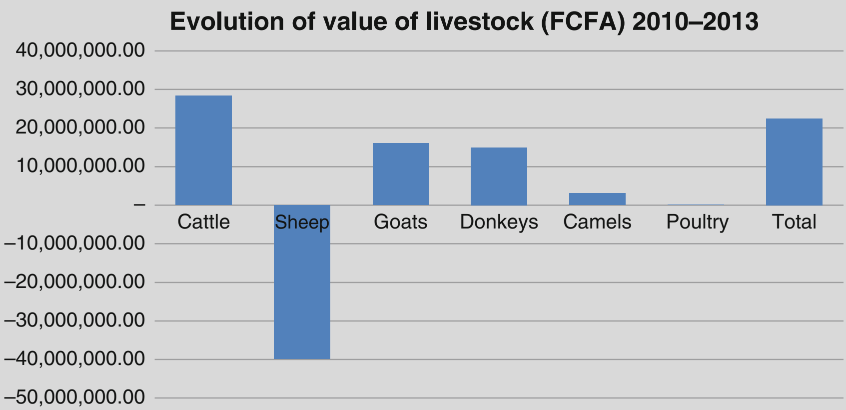
Just like with agricultural production, the evolution of livestock headcount and livestock revenue needs to be compared against the counterfactual. A decrease of livestock headcount could be considered as a negative evolution only if the counterfactual scenario is a stable or increasing number of livestock. However, in many circumstances, a business-as-usual trend might actually consist of a greater decrease of the stock. In this case, anything over and above this decrease could be considered a positive impact.

The main economic findings are presented in Table 2.

On average, the empirical data suggests that there has been a positive evolution of yearly household budget as well as yearly savings, albeit to a lesser extent. These findings are in line with existing development literature which suggests that the ability of the poorest households to save is very low. This is due to the fact that a household with a low income is more likely to spend extra income rather than save it, so although savings do increase with income, they do not do so proportionally.

Finally, households were asked to estimate how much time they would need to replace lost income and assets following a significant drought event pre- and post-ALP intervention. This was done by asking communities how much time it took them to replenish their stocks after the last drought event and how much time they thought this would have required if ALP had been operating during the last drought event. Responses suggest a faster recovery rate of nearly half the time following ALP.

Box 3: Average Income from Livestock and Evolution of Value per Type of Animal (FCFA, 2013)



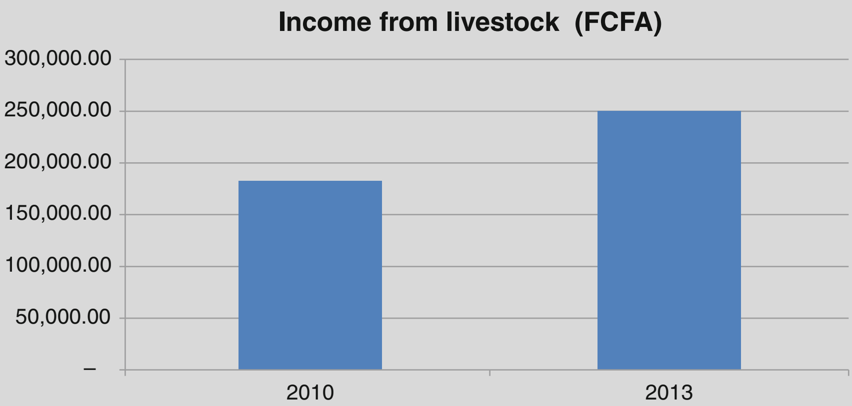


Table 2 Main economic findings

	2009 (pre-ALP)	2013 (post-ALP)	% change
Average yearly household budget *(FCFA 2013)*	266,449	399,353	+49.8
Average yearly savings, including in-kind savings *(FCFA 2013)*	63,083	86,056	+36.4
Average time required to replenish lost income and assets after a drought	4.6 years	2.5 years	−44.7

Social Outcomes

The main focus of ALP's work is on generating social outcomes. The empirical work was therefore aimed at capturing these social outcomes based on the theory of change which had been developed with the community. When measuring social outcomes, some are easy to quantify based on established academic methods – such as health and education – while other softer social outcomes such as social capital, institutional capital, or changes in gender dynamics are harder to quantify. However, such soft indictors should not be overlooked due to the difficulty in quantifying them as they are no less important in building resilience or in enhancing development more broadly. Institutional strengthening, for example, can create positive externalities such as community members' participation in decision-making as well as broader economic outcomes. Another example is women's economic empowerment which is known to drive socioeconomic change. Furthermore, it is widely acknowledged that building resilience is not just about creating changes in material conditions but is a multidimensional process which involves the flexibility of institutions, of social structures, and of collective knowledge and skills in communities. The changes in social outcomes are presented in Table 3 below.

The indicators which have been used for health and education are the ones which are well established in the respective fields of health and education economics. Quality-adjusted life years (QALYs) were calculated by asking sample households to rank their health condition both on physical and mental health grounds (see Box 4). To capture a change in education, the number of children attending school was combined with the average school attendance in order to obtain the extra school years gained (Fig. 13).

Social capital was measured by assessing the evolution of solidarity circles of households, i.e., the number of other households directly supporting the livelihoods of the sample households. An enlargement of this circle is used as a proxy indicator for social capital within communities. Subjective indicators were also used to capture the community perceptions of changes in the evolution of women's role on decision-making structures and the evolution of trust in household and community adaptive capacity.

Table 3 Evolution of key social variables

Type of outcome	Indicator	% evolution (2009–2013)
Health	Quality-adjusted life years (QALYs)	+128
Education	Number of children attending school >6 months per year	+33
Social capital	Number of persons in the "solidarity network" of the household	+23
Gender (and institutional capital)	Five-point scale on the extent to which women have an influence in community and household decision-making	+112
Adaptive capacity	Five-point scale on the extent to which community members believe in their capacity and knowledge to establish resilience strategies in the future	+258

Box 4: Quality-Adjusted Life Years

The QALY is a measure of the value of health outcomes. Since health is a function of length of life and quality of life, the QALY was developed as an attempt to combine the value of these attributes into a single index number. The basic idea underlying the QALY is simple: it assumes that a year of life lived in perfect health is worth 1 QALY (1 year of life $\times$ 1 utility value $=$ 1 QALY) and that a year of life lived in a state of less than this perfect health is worth less than 1. QALYs are therefore expressed in terms of "years lived in perfect health": half a year lived in perfect health is equivalent to 0.5 QALYs (0.5 years $\times$ 1 utility), the same as 1 year of life lived in a situation with utility 0.5 (e.g., bedridden) (1 year $\times$ 0.5 utility). QALYs combine subjective data (e.g., self-stated physical and mental health conditions) with objective data (e.g., life expectancy) to measure the disease burden associated with different health conditions. It can also be used for measuring the value of different health conditions – notably in cost-benefit analysis – through a combination of the empirical data obtained and measurement of the "statistical value of life."

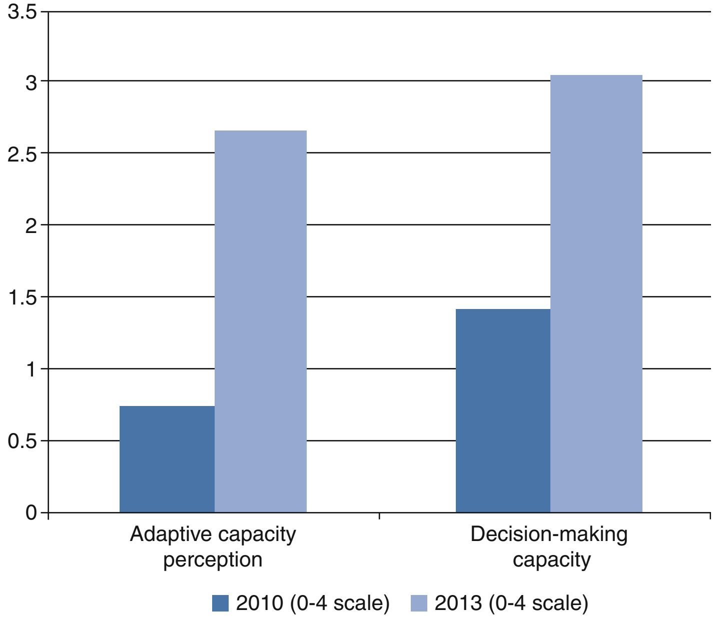


Fig. 13 Change in perception of adaptive capacity for men and women and decision-making for women only

Table 4 Evolution of key environmental indicators

Outcome	Indicator	Evolution (2009–2013)
Avoided deforestation and reforestation	Number of trees planted or maintained	+64,165
Improved land management	Hectares of degraded lands restored	+1,575.6

Key Environmental Outcomes

The two environmental outcomes which were measured in this research both relate to desertification which is the greatest ecological threat facing Sahel ecosystems. ALP has tried to address this challenge through building the capacity of households to implement sustainable land management techniques, providing resources for reforestation, avoiding further deforestation, and restoring of degraded lands.

The environmental outcomes are intricately linked to the ecosystem services that are directly supporting the socioeconomic livelihoods of the communities. For example, reforestation and deforestation can directly provide resources such as timber and fodder to communities. Equally, sustainable land management and the restoration of degraded lands can avoid a further extension of agricultural land to less productive spots. Finally, both can affect microclimate patterns in the communities. The results of the environmental outcomes are presented in Table 4.

According to the data, the number of trees maintained (not deforested) or planted since the start of the program amounts to approximately 64, 165 in the four communities. This equates to an average of 75 trees per household. A total of 1,575 ha of degraded lands have been restored. This represents an average of 1.85 ha per household.

Measuring Additionality

The outcome data presented so far is only representative of "gross impact," i.e., the total impact across different forms of capital before you take into account what would have happened in the "counterfactual" or if a business-as-usual approach had been followed and ALP had not implemented CBA approaches in Dakoro. Determining the counterfactual makes it possible to estimate the role of the ALP in creating outcomes. This allows for calculation of the "net" or "additional" impact.

Due to the nature of the number of active stakeholders in Dakoro, this study asked communities to list the organizations and actors that contributed to the changes observed and to estimate the proportion of contribution from these different actors to the outcomes. The results are presented in Table 5 below.

It is interesting to note that communities perceive the impact of ALP differently for each outcome. ALP is perceived to have had the most impact in creating positive

Table 5 Proportion of contribution of different organizations operating in the area

	Economic impacts	Social impacts	Environmental impacts
Local government	9	7	8
ALP	**53**	**55**	**60**
Other NGOs	15	14	11
State programs	15	18	14
Community actions	8	6	7
Total	100	100	100

environmental outcomes rather than social or economic ones. It is also important to note that there is a risk of social desirability of answers in this sort of exercise, meaning that respondents answer according to what they think the interviewer wants to hear, and it is possible that respondents in this research provided socially desirable answers. However, it is also worth noting the value of subjective questions which provide an opportunity for communities to share their perspective and perception. These answers therefore are assumed to be indicative and they are fed into the analysis of the counterfactual.

While these results are important and a useful exercise, they do not capture evolution due to climate variability. 2009 was a bad year overall for average rainfall and duration of the rainy season. The four following years were relatively good which might explain in part the increase in agricultural and livestock revenue and, by extension, the improvement in social and environmental conditions in the communities (see Box 5).

Therefore it is important to capture the counterfactual; in order to do this, two methodological approaches were considered:

Option one: using national-level data on the evolution of agriculture and livestock production and productivity and comparing this data to observed changes in ALP communities

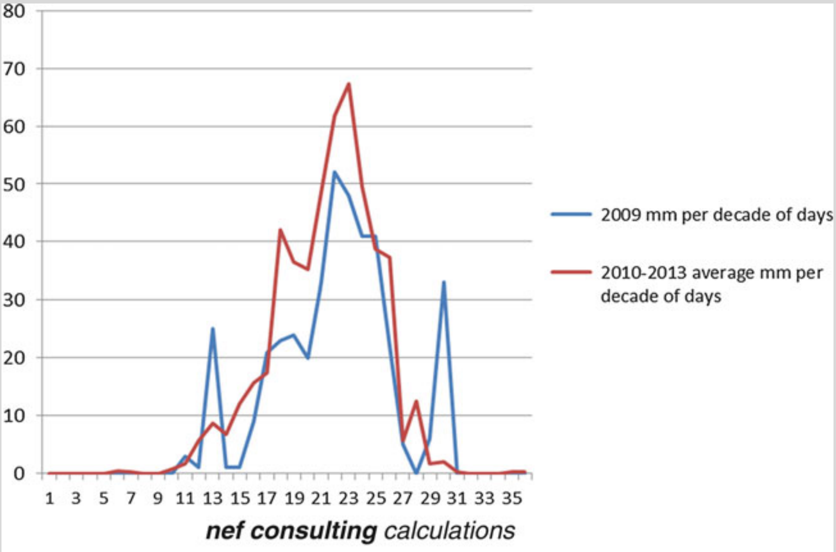
However this approach could involve substantial biases. Firstly, national (or even regional) data can mask substantial disparities in production and productivity among different sites and locations, for example, comparisons between production in marginalized communities and production in areas with relatively intensive/modern practices. This means that aggregate averages might be poor proxies for understanding what would have happened in marginalized communities in Dakoro in the absence of ALP. Secondly, as articulated earlier, despite an increase in total agricultural production throughout the past three decades, the existing evidence suggests that production per capita has been decreasing (Ozer 2007). Given that the data gathered by this research is for household-level agricultural production, it is neither comparable to per capital production nor aggregate production figures. Therefore, benchmarking the change in agricultural production, relative to national-level data, was excluded due to a lack of directly comparable data.

Box 5: 2009 Versus Post-2010 Rainfall Patterns

Rainfall evolution (2009–2013)

	mm of rain	Days of rainfall (events with >5 mm)
2009	409	44
2010	539	59
2011	479	44
2012	571	52
2013	448	43

Rainfall pattern and variability



Option two: using regression analysis to understand the extent to which evolving climate patterns might have determined the increase in production and productivity

This method can be used to estimate the extent to which the observed increase in production can be explained by weather patterns across different years and therefore provide an estimation of the production that should have been expected had the intervention not taken place. Despite this approach being more robust, it is important to stress that regression analysis is dependent to a great extent on the quantity and quality of available data. For instance, although climate patterns are sufficiently documented, the occurrence of other external shocks, such as locusts, is poorly reported – beyond whether they occurred or not. However, this approach was considered less imprecise than option one.

Due to the limits of the first option, this study used regression analysis to determine the contribution of climate evolutions to agricultural production and livestock. This was done by using a historical data series for the region of Maradi, the closest possible to Dakoro (see Figs. 14 and 15).

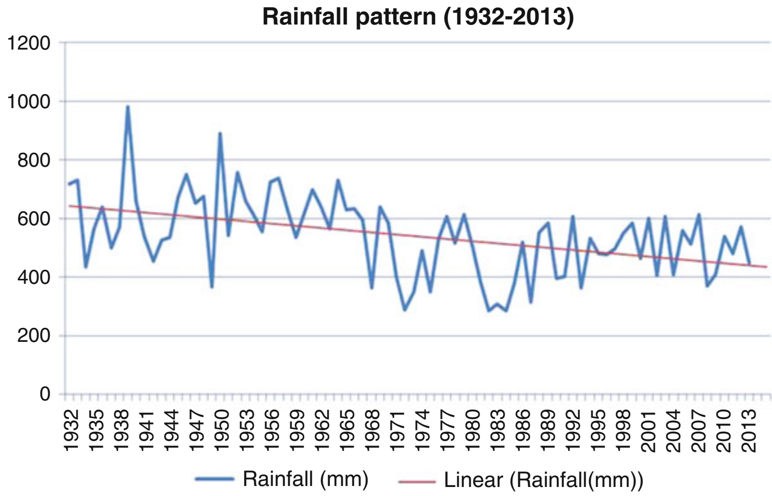


Fig. 14 Rainfall pattern Maradi (1932–2013)

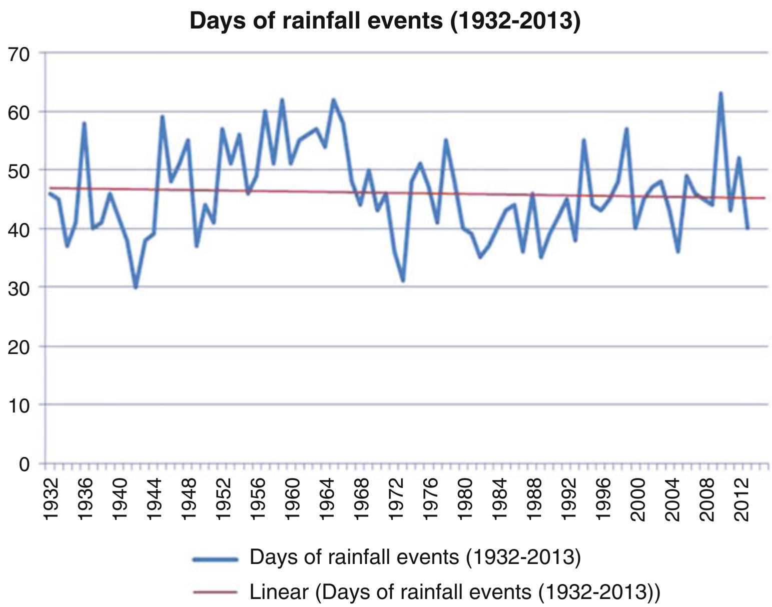


Fig. 15 Days of rainfall events Maradi (1932–2013)

Table 6 Measurement of the counterfactual for major crop production (expressed in kg)

Crop	Production 2009	Estimated 2013 production under BAU	Actual production 2013 (ALP)	Gross impact of ALP	Net impact of ALP
Millet	267,053.88	271,733.88	307,584.03	+40,530.16	+35,850.16
Cowpeas	81,993.42	86,673.42	141,207.48	+59,214.06	+54,534.06
Sorghum	123,304.26	127,984.26	129,470	+6,165.74	+1,485.74

The results suggest that for each extra mm of rainfall, 120 additional units of agricultural output are generated. Conversely, a decrease of 1 mm in rainfall induces a loss of 120 units of output. By using this coefficient for the period 2009–2013 in the sample communities, it was determined that agricultural production for the three major crops (millet, sorghum, and cowpeas) should have been expected to increase by 3.75 % throughout the period 2009–2013, compared to 30.80 % as the findings suggest. As such, the net increase (impact due to ALP) is of the order of 27 %. Taking into account the contribution of other actors to the program, ALP has directly contributed to a 13.8 % increase of agricultural production. Table 6 presents the counterfactual for all major crops and the net impact of ALP.

A similar approach was replicated to determine the quantitative link between livestock returns and rainfall patterns. The coefficients determined for economic capital were then transposed to social and environmental capital to calculate net impact. Although not a precise approach, this was deemed to be the most robust way of assessing the business-as-usual scenario and environmental capital evolution. The net economic, social, and environmental impacts of ALP, factoring for counterfactual and attribution, are presented in Table 7 below.

Approach to Social Cost-Benefit Analysis

Determining what is included and excluded from a socioeconomic analysis is of critical importance in order to understand the results of a social cost-benefit analysis. The approach taken in this analysis can be summarized as follows:

- **To include not only strict economic outcomes but also broader social and environmental outcomes**. Such an approach therefore considers three forms of capital (economic, social, and environmental) rather than just one. This requires the monetization of social and environmental outcomes in order to be compared like-for-like with economic outcomes and with investment in the program. Although monetization of nonmarket goods entails uncertainties, excluding these from the analysis means that an entire range of benefits become automatically invisible. In short, while accepting the shortcomings of "pricing the priceless," this analysis takes the stance that an imprecise number is better than excluding outcomes which matter to communities.

Table 7 Net outcome incidence per indicator per form of capital

	Outcome	Indicator	Outcome incidence	Deadweight	Attribution	Net outcome incidence
Economic benefits	Agricultural revenue	Net evolution of revenue	£153,273.72	0.27	0.53	£21,857.25
	Livestock revenue	Net evolution of revenue	£74,397.87	0.27	0.53	£10,609.34
	Total savings (stock)	Stock of savings (money and nature/ livestock)	£30,312.49	0.27	0.53	£4,322.64
Social benefits	Health	Quality-adjusted life years gained	70.80337673	0.27	0.53	10.10
	Education	School years gained	93.08	0.27	0.53	13.27
	Social capital	Additional funds provided to other community members	£60,013.52	0.27	0.55	£8,912.67
	Empowerment	Increased confidence in making adaptation decisions	0.384615385	0.27	0.55	0.057119665
	Gender empowerment	Decision-making capacity within household	0.323076923	0.27	0.55	0.047980519
Environmental benefits	Avoided land degradation	Hectares under improved land management	1,576	0.27	0.60	255.6992197
	Avoided deforestation	Number of trees planted or maintained	34,649	0.27	0.60	5,622.853735

- **To focus on a restrictive set of outcomes that can reflect broad aggregates or the “big picture” for communities and decision-makers rather than an exhaustive list**. This means not focusing on the turnover of hedging schemes or the impacts of micro-lending within the community, for example, investigating instead whether and to what extent this set of micro-interventions have influenced broad aggregates such as revenue, health, or education. This responds to a need to replicate the analysis in different contexts, which is made possible by establishing a common set of outcomes that can be used in other contexts.
- **To consider not only strict typical disaster risk reduction outcomes but equally more classic development outcomes**. Indeed, the frontiers between an adaptation intervention and a development one are blurred and often artificial. As such, it is sensible to consider whether and to what extent adaptation enhances human development and vice versa.
- **To create the framework for the analysis in the spirit of community-based adaptation**. The outcomes and impacts have been co-determined through a bottom-up process, and only then complemented with objective indicators, in order to measure what matters.

Table 8 outlines the variables used in the SCBA, as well as valuation approaches and sources. An overview of the process is presented in Fig. 16 below.

As outlined earlier, this analysis considers both the counterfactual and the potential contribution of other actors, including the autonomous strategies of communities, to the outcomes identified. The benefits generated by the intervention are then compared to the financial investment of ALP in the communities. Financial costs include both programmatic expenditure and management costs associated with these.

Time Delineation

The study involved running two distinct modeling simulations:

- A strict **evaluative simulation** that focuses only on the costs borne and benefits generated throughout the period 2010–2013.
- An analysis **combining evaluative data with a forecast to 2020**. While the results of the former can be considered more reliable and the latter more hypothetical, there is a clear rationale for forecasting potential impacts into the future.

Firstly, benefits do not suddenly cease to occur as a consequence of artificial time delimitations. For instance, the impacts of the introduction of improved crop varieties are unlikely to stop happening this year. As such, analyzing up to 2013 only may considerably underestimate the benefits generated by community-based adaptation. Indeed, one of its key characteristics is the focus on sustainability: by embedding new practices, knowledge, and skills into community structures, community-based adaptation aims precisely to ensure the sustainability of adaptation beyond the time span of ALP’s intervention.

Table 8 Description of variables used in the social cost-benefit analysis

Category	Variable	Indicator	Data collection method	Monetary valuation proxy	Source for valuation proxy
Economic	Agricultural revenue	Net returns to agriculture (market and subsistence)	*Empirical*	Market value	Empirical
	Livestock revenue	Net returns to livestock (market and subsistence)	*Empirical*	Market value	Empirical
	Savings	Monetary and in-kind stock of savings	*Empirical*	Market value	Empirical
Social	Health	Quality-adjusted life years (QALYs)	*Empirical*	Statistical value of life approach (average GDP per capita of Niger for a full QALY, i.e., year in perfect health)	Miller (2000)
	Education	Extra years of schooling	*Empirical*	Returns to primary education for an extra year of schooling	Psacharopoulos and Patrinos (2002)
	Social capital	Number of individuals in the solidarity circle	*Empirical*	Value of goods donated to other households within the community per year	Empirical (questionnaire application)
	Women's participation	Increased participation of women in decision-making	*Empirical*	Willingness-to-accept compensation exercise	Empirical (focus groups)
	Community empowerment	Increased confidence in implementing adaptation strategies	*Empirical*	Opportunity cost of time (hourly minimum wage) for participation in community actions and decision-making	Empirical
Environmental	Avoided deforestation and reforestation	Number of trees planted/ maintained	*Empirical*	Value of timber	World Bank (2009)
				Value of fodder	
				Value of tCO2eq emissions sequestrated	
	Restoration of degraded/ desertified lands	Hectares of land restored	*Empirical*	Value of land per hectare (market price)	Empirical

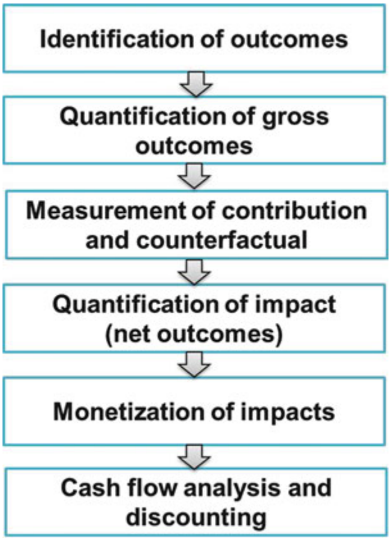


Fig. 16 Flow diagram illustrating the social cost-benefit analysis process

In short, although an evaluative model may be perceived to be "safer" in terms of deriving conclusions on strategies that are already in place, forecasting into the future can, despite complexities, depict a better representation of the magnitude of benefits.

Forecasting and Uncertainty

Forecasting into the future requires a consideration of likely climatic evolutions over the next 7 years. Indeed, the evolution of economic capital (and, by extension, social and environmental capital) is critically dependent on climate variables – most importantly rainfall patterns. As evidenced earlier, however, the rainfall and temperature patterns in Dakoro are far from linear and do not point to a clear trend. Similarly, the available data does not show clear trends in the distribution of rainfall during the rainy season as well as demonstrates potential interruptions to the start/end dates of the rainy season.

Numerous scenarios are therefore required in order to forecast uncertainty and the evolution of capital, and these need to be based on historical data. These scenarios are outlined in Table 9.

A "no drought" scenario was excluded from the analysis. This is because Dakoro has experienced six severe or catastrophic droughts in the past 29 years. This represents a frequency of one drought every 4.8 years, on average. It is also synonymous with a 20 % probability of drought occurrence per year.

Through datasets of the Nigerien climate center Agrhymet, the study was able to determine the impacts of shocks on agricultural production for the region of Maradi. Through an econometric analysis, the impact of the level of rainfall on agricultural production and livestock was estimated. The coefficients derived

Table 9 Different scenarios for a forecastive analysis

Scenario	Description
Replicating the 1980s scenario (worst case)	An average rainfall of 411.5 mm per year throughout the period and four major drought events – three of which consecutive
Replicating the 1990s scenario (moderate case)	An average rainfall of 489 mm per year throughout the decade and one major drought event
Replicating the 2000s scenario (best case)	An average rainfall of 495.2 mm throughout the decade and one major drought event

allowed for forecasting the evolution of production under a business-as-usual scenario (what would have happened without ALP) compared to the evolution of production post-ALP. While, evidently, community-based adaptation does not shield nor exempt communities from shocks, a higher level of savings and other initial conditions prior to the shock mean that the reduction can be less dramatic and that communities are apt to bounce back more rapidly, as evidenced earlier.

Findings

Table 10 presents the results of the evaluative analysis for the four communities combined. The results suggest that under any discounted rate, the intervention yields highly positive returns even if not taking into account further impacts beyond 2013.

More importantly, even if accounting *only* for economic returns, cost-benefit ratios range from 1.9 to 2.06. That is, even when social and environmental impacts are left out of the equation, the intervention still yields between £1.9 and £2.06 per pound invested. Further, returns are still positive at the highest discount rate of 12 %, with economic capital representing most of the value (see Fig. 17).

When forecasting over a longer time span, the benefits of the program increase even further (see Table 11) and this is due to a combination of two factors:

1. The investment period of ALP ends in 2014, while benefits continue to accrue to communities. The net benefits therefore increase compared to costs, which remain stable after 2014.
2. A critical assumption in the model is that the time required to recover from a drought post-ALP is approximately half that required in a no intervention scenario (2.5 years vs. 4.6 years). This substantially increases the output gap between the business-as-usual and the intervention scenario. It also means that the worse the climate scenario, the higher the returns generated by community-based adaptation (see Table 11). When relaxing this assumption, by assuming that the same time is required to recover regardless of the intervention, then returns are still positive, albeit lower.

Table 10 Results of evaluative analysis (time span: 2010–2013) *in £2013*

	Net present value (net discounted benefits)	Cost-benefit ratio
0 % discount rate	£184,129.84	4.45
5 % discount rate	£158,044.91	4.34
12 % discount rate	£129,330.39	4.19

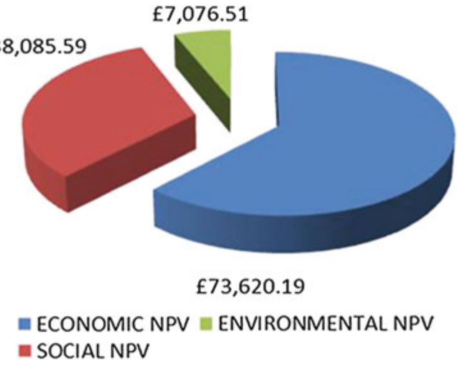


Fig. 17 Net present value of different capitals under a 12 % discount rate

Table 11 Results of combined evaluative and forecastive analysis (time span: 2010–2020) *in £2013*

		Net present value (net discounted benefits)	Cost-benefit ratio	Economic C-B ratio only
The 1980s scenario (worse)	0 % discount rate	£399,413.48	9.8	4.5
	5 % discount rate	£340,751.38	8.5	3.9
	12 % discount rate	£230,426.50	6.1	2.8
The 1990s scenario (moderate)	0 % discount rate	£321,080.23	7.9	3.6
	5 % discount rate	£273,922.99	6.8	3.1
	12 % discount rate	£185,235.10	4.9	2.3
The 2000s scenario (best)	0 % discount rate	£286,934.97	7.06	3.2
	5 % discount rate	£244,792.66	6.1	2.8
	12 % discount rate	£165,536.28	4.4	2.06

These results need to be put into perspective. Table 12 compiles the results of a sample of previous cost-benefit analyses on adaptation and DRR programs. The results from this analysis suggest that ratios ranging from approximately £4 to almost £10 per pound invested are indicative of a highly socially profitable investment. Indicatively, the ratios found in this study are indeed higher than the

Table 12 Indicative cost-benefit ratios of a sample of DRR and climate adaptation interventions

Country	Type of intervention	Cost-benefit ratios	Source
Nepal	Adaptation	1.13–2.04	Willenbockel (2011)
Nepal	DRR	1.55–5.81	White and Rorick (2010)
India	DRR	3.17–4.58	Venton (2004)
Sudan	Adaptation	2.4	Khogali and Zewdu (2009)
Malawi	Adaptation	37.3	Tearfund (2010)
Belarus, Georgia, and Kazakhstan	DRR	3.1–5.7	World Bank (2008)
Kenya	Adaptation	0.93–3.13	Nicholles and Vardakoulias (2012)

Source: NEF Consulting compilation

ratios of all previous analyses except for one, which suggests an extremely high result $37.3 per $1 invested. However, this analysis does not consider explicitly the counterfactual and attribution, which means that results might overestimate the benefits of the program compared to costs. Further, this comparison is only indicative. Indeed, these studies are not comparable like-for-like: first and foremost because the outcomes they consider are different and second because the time frames considered are highly variable among different analyses.

Conclusion

This research aimed to answer the question: is community-based adaptation an efficient and effective approach to climate change adaptation? While previous research conducted by NEF Consulting, published in the report *Counting on Uncertainty* (Nicholles and Vardakoulias 2011), was based on a solely forecastive approach (the impacts of strategies which had not yet taken place), this research is based on solid, evaluative data. The findings from this suggest that returns are considerably higher than the ones which were previously predicted. Returns on investment range from £4 to almost £10 per £1 invested, which is high by any standard. There is a high level of confidence in these results for two main reasons:

1. The sensitivity analysis conducted suggests that even if considering strict quantitative economic benefits only, returns are still positive. As such, even for those skeptical of monetization (i.e., those who do not place confidence in nonmarket valuation), the fact that economic returns are positive on their own is sufficient to consider community-based adaptation as cost-effective.
2. This analysis has taken into extensive consideration both the counterfactual and the contribution of other actors in achieving the outcomes identified in the field. It is therefore highly unlikely that impacts are overestimated or inflated.

Considering the breath of positive outcomes presented in this analysis, community-based adaptation approaches appear to present multiple dividends: not only does a community-based approach enhance the decision-making capacities of communities at a local scale but equally impacts considerably on "hard" outcomes, such as increase of agricultural production. This means that a community-based approach seems to increase the "uptake" of adaptation and development activities, e.g., the introduction of improved seed varieties.

Similarly, community-based adaptation impacts on overall development of communities. Indeed the benefits considered in this analysis are based on typical development outcomes such as health and education. The findings suggest that community-based adaptation responds both to short-run disaster mitigation measures and long-run development needs.

Finally, the approach and findings from this study have led to a number of recommendations for future upscaling of the analysis and design of adaptation strategies:

- Replicate the analysis to appraise and evaluate different adaptation strategies. Comparing results across different adaptation interventions could indicate the most cost-effective adaptation strategies.
- Determine a common set of outcomes which should be considered when evaluating adaptation interventions. Only this would allow a robust comparison of different socioeconomic appraisals.
- Take note that wide uncertainties regarding climate variables, such as future rainfall and temperatures patterns, mean that different scenarios need to be considered when forecasting the impacts of adaptation interventions into the future. This especially holds for analyses at a local level, where climate uncertainties are considerably high.

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Adaptation as Climate Risk Management: Methods and Approaches

Paul Bowyer, Michaela Schaller, Steffen Bender, and Daniela Jacob

Contents

Abstract

This chapter highlights the benefits of framing adaptation to climate change as an issue of climate risk management and describes a number of methods and approaches that may be applied in the process of developing adaptation strategies. A key consideration when developing adaptation strategies is to have a sound understanding of how a given system functions in response to changes in

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both climate and non-climate factors, and thus the need for a causal model which represents this understanding. There are a range of methods and tools that may be applied to assist with developing this system understanding in a climate risk assessment, and a number of these are described here. Moreover, given that adaptation planning is to a large degree about forward planning, all adaptation strategies will need to appropriately consider the implications of uncertainty on their likely effectiveness. This chapter provides a discussion of the ways in which adaptation strategies can be developed and decisions made when appraising different adaptation strategies. As such, it provides a basis upon which users can assess how they may approach adaptation as an issue of climate risk management and select and apply suitable methods. It provides a useful accompaniment to any practitioner or organization, as they proceed on their adaptation journey.

Keywords
Risk management • Climate change • Adaptation • Climate information • Impact assessment • Adaptation assessment • Robust decision making • Uncertainty

Introduction

Adaptation is an iterative process of defining a problem, planning and implementing action, and monitoring and reviewing these actions, in the light of new or changing risks, regulations, policies, and/or new information about a given system response. Adaptation action involves making changes in management practices and business systems in order to reduce the potential for harm or negative consequences and maximize or exploit any opportunities or positive consequences that may arise under climate change (Adger et al. 2007). These actions may range in size from relatively small changes, or larger transformations, depending on the size and scale of the adaptation problem.

Adaptation will need to take place in order to cope with the impacts of climate change over the shorter term, e.g., due to climate variability and extremes, and to ensure that business objectives are able to be met over the longer term, and thus will involve long-term forward planning. Moreover, adaptation to climate change is not just about thinking in terms of how the climate may change in isolation. Adapting to the impacts of climate change should be integrated into all climate-sensitive areas that an organization may have, and thus any adaptation actions will need to fully consider the non-climate factors that are key to understanding the impacts of climate change in their proper context. Only by doing this will a sound foundation be laid for developing adaptation measures and strategies. Dealing with adaptation as part of an overall organizational risk management strategy should ensure that climate impacts are not considered in isolation, and make it easier to address adaptation as an issue of risk management.

It is also important to state that adaptation may not be successful. The success of adaptation will depend on a wide range of factors including the size and/or complexity of the problem, good governance structures, adequate resourcing, a sound understanding of system function, and appropriate incentives (Moser and Boykoff 2013). Chief among these factors will be the size and complexity of the problem. The larger the changes in climate and associated impacts, the less likely it is that adaptation will be successful as physical, technical, and social limits of adaptation are approached (Dow et al. 2013). This discussion leads to a suitable definition of adaptation as:

> Adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting nonclimatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities. Moser and Ekstrom (2010)

Adaptation is about forward planning in both the short and long term and as such involves large uncertainties: these include uncertainty about the possible future climate, uncertainty about the possible future development of human society, uncertainty in understanding the sensitivity of a given system to changes in climate and non-climate factors, and uncertainty around the effectiveness of any adaptation strategies that may be implemented. These uncertainties need to be appropriately considered when developing adaptation strategies. These characteristics of adaptation make a risk management framework particularly well suited to dealing with adaptation (Jones and Preston 2011). This chapter provides an overview of the risk management process within an adaptation context, a summary of key issues, and methods and approaches that may be applied at the risk assessment and adaptation appraisal stages of the risk management process. As such, this chapter provides a useful accompaniment to any practitioner or organization, as they proceed on their adaptation journey.

What Is Risk and the Risk Management Process?

The International Standards Organization (ISO) 31000 (2009) defines risk as the "Effect of uncertainty on objectives." Organizations will have a wide range of objectives which operate under conditions of uncertainty, and the impact that this uncertainty has on being able to successfully meet objectives is the focus of the risk management process. These objectives include strategic objectives, such as the reputation of an organization with its stakeholders; operational objectives such as meeting certain levels of service provision, e.g., ensuring a reliable water supply to a city or region; and objectives relating to compliance with legal and regulatory requirements, e.g., chemical concentrations in industrial effluents or water discharge temperatures. All of these kinds of objectives may be influenced in some way by changes in climate.

In this chapter, the ISO 31000 (2009) calculation of risk is used, being the combination of the likelihood of an event and its consequences:

$$\text{Risk} = \text{Likelihood} * \text{Consequences}.$$

If the likelihood of a given event is assessed as being zero, then there is no risk; likewise if there are no consequences from an event, then the risk is also zero. Generally, when the likelihood and consequences are higher than the greater the risk, however, things are more complicated than this, as the significance of a given level of risk is what matters to organizations, when deciding whether the risks need treating.

The consequences of an event may be positive, which may sometimes be referred to as opportunities, or negative, which may be referred to as threats or vulnerabilities. In this chapter, threats and opportunities are used to refer to negative and positive consequences, respectively. An organization may face more than one event which presents a risk to the achievement of objectives, and managing one risk may have implications for the management of other risks, and so it is important to consider risk interactions – this is particularly relevant for reducing the potential for maladaptive strategies. The likelihood of an event can be assessed in qualitative or quantitative terms.

In the context of risk and vulnerability, it is worth stating that in the climate adaptation research arena, a lot of effort has been devoted to investigate the vulnerability of various countries and communities to climate change, to the extent that it has become a widely applied method (Malone and Engle 2011). For adaptation in practice, a risk management framework can incorporate vulnerability analyses as part of a risk assessment.

Regardless whether the risks that a given organization may face have positive or negative consequences, in order to adapt to climate change, a coherent framework is needed within which these risks can be managed. The risk management process provides such a framework. The ISO 31000 (2009) defines the risk management process as the:

> Systematic application of management policies, procedures, and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring, and reviewing risk. (ISO 31000 2009)

The various stages involved in the risk management process and their interconnections are shown schematically in Fig. 1. The focus of discussion in this chapter is on the risk assessment stage and assessing adaptation measures as part of the risk treatment stage (Fig. 1).

What Are the Benefits of a Risk Management Approach?

There are various reasons as to why adopting a risk management framework to address adaptation to climate change is attractive and powerful; these include (adapted from ISO 31000 2009; Jones and Preston 2011):

- **It is all about uncertainty**: adaptation to climate change is characterized as operating under uncertainty and deep uncertainty, in relation to the future development of climate and socioeconomic systems, and what this may mean

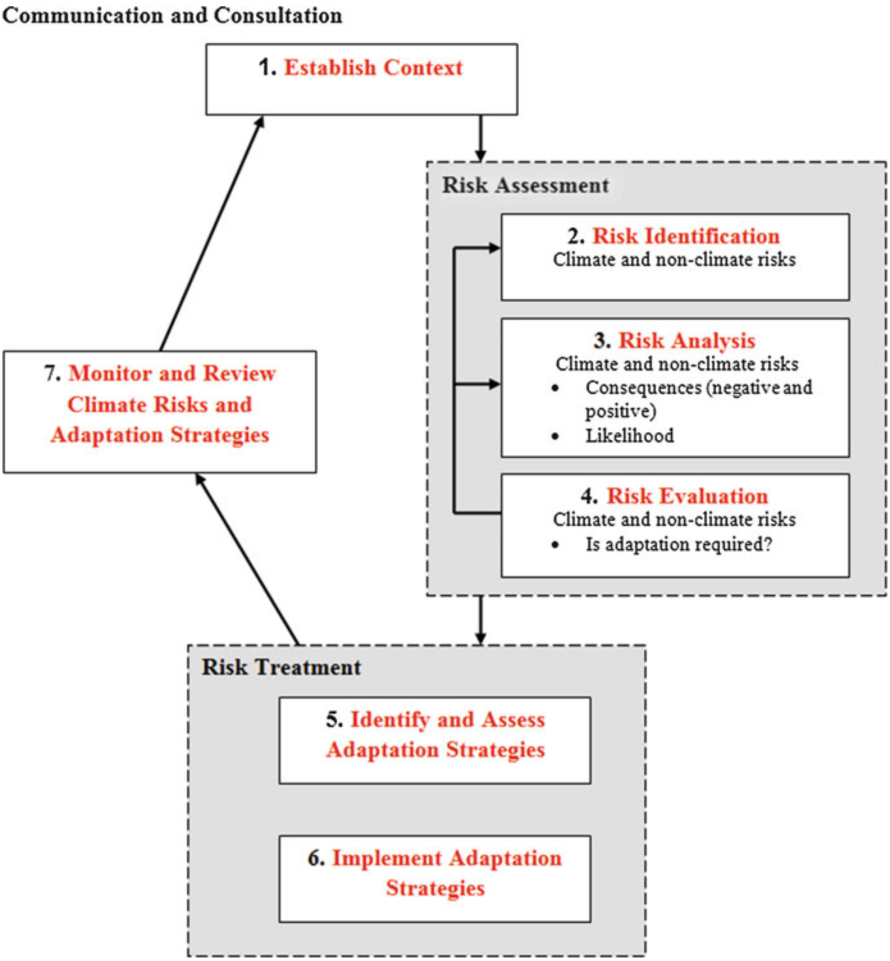

Fig. 1 Adaptation as a process of risk management. The various stages involved in the risk management process and their interactions, as applied to climate change adaptation (*Source*: Adapted from the ISO 31000 (2009) risk guidelines. The risk management process may not proceed in a linear process from step 1 through 7, and in practice steps 3 and 5 may be performed in combination. The steps are separated out simply to enable clarity of explanation

for a given organization. A risk management framework involves explicit consideration of uncertainty in climate risks, their likelihood, and consequences.

- **It is solution focused**: adaptation is about taking action in the real world, reducing threats, and seizing opportunities presented by climate change. This means finding and implementing effective solutions. The risk treatment stage in the risk management process makes this focus on finding solutions explicit. In addition, in relating the level of risk determined in the risk analysis to what is significant for an organization, a rational basis is provided on which to stimulate action.

- **Communication and consultation is integral**: key to developing effective solutions is establishing the proper context for identifying risks, having sound causal models of how a system functions, and identifying and being able to implement adaptation strategies. All these activities demand that there is effective communication and consultation with a range of people, to ensure that the right people are on board in gaining knowledge and understanding, formulating and asking the "right" questions, and identifying practical adaptation strategies and any potential for maladaptation.
- **It is a well-established method:** risk management is not new, and many businesses and organizations will already have risk management strategies in place. As such, it may be possible to incorporate climate risk existing mechanisms rather than requiring new mechanisms to be implemented. This familiarity can aid the uptake and mainstreaming of adaptation into all relevant business activities and can increase the chances of considering climate as an additional factor in managing risks.
- **It is an iterative process**: adaptation takes place in a dynamic environment where external and internal factors change over time, there are deep uncertainties, and new information is developed which may be brought to bear in informing decision making. As such, adaptation is a continual process and as such requires an iterative process.
- **It is flexible**: a range of different methods may be applied to the discovery and generation of information in relation to climate impacts and considering and planning adaptation options. Thus, the risk management process can be tailored to the information needs and level of detail required to analyze a particular adaptation problem.
- **Facilitates a learning environment**: while a range of different methods can be applied in carrying out a risk assessment (described in section "Methods and Tools for Climate Risk Assessment"), it is the case that the very act of committing to a process of considering how changes in climate (and other factors) may impact on business objectives can provide an environment in which much learning about how an organization operates is obtained. In addition, where the adaptation problem involves a range of stakeholders with different values and perspectives, the process provides a forum in which these issues can be discussed, networks built, and knowledge shared and contested, thus facilitating social learning (Yuen et al. 2013). The process will also generate learning about which factors were instrumental in being able to engage with stakeholders, and possibly arrive at mutually agreeable adaptation strategies.

That a risk management process provides an attractive framework for approaching adaptation is also evidenced by its use in other countries, for example in the UK (Willows and Connell 2003). Adopting a risk management framework was also one of the recommendations from the US national research project, *America's Climate Choices* (NRC 2010), which sets out the direction in which the USA should deal with climate change.

Methods and Tools for Climate Risk Assessment

In order for an organization to assess how their business objectives may be affected by changes in climate, and other non-climate factors, and thus understand how large a threat or opportunity may exist, methods and tools are needed with which an evidence base can be generated to help answer these questions. Understanding how a given system responds to climate and non-climate factors is central to successful adaptation planning. The greater the understanding of how a given system functions, the more guidance there is as to which factors could be acted upon in order to manage the risk and thus aid the search for, and development of, successful adaptation strategies. Consequently, all risk assessments need a causal model that links the changes in climate and non-climate factors to the risks. These models can vary from conceptual to quantitative impact models (Jones 2001; Jones and Preston 2011).

It is the case that there will be many adaptation problems and issues that are so complex that there will not be existing quantitative impact models available for a given system. Thus, it may be necessary to develop a new model, or modify existing models, if a quantitative approach is sought. Alternatively, an adaptation problem may be so complex and poorly quantified that it will be necessary to generate conceptual models whereby the way in which expected changes in climate may impact a system is thought through, using methods such as brainstorming sessions, workshops, and logical reasoning.

The choice then as to which method or tool to use will depend upon a number of factors, chief among which will be the complexity of the adaptation problem (which may mean a complex or more simple method is pursued), the available resources (time, financial, expertise), and the nature of the uncertainty involved in the problem (ISO 31010 2009).

While it should be clear that the kinds of climate risks that organizations face are generated by both climate and non-climate factors, there is a focus, in this section, on describing those methods and tools that may be used to investigate what the impact of changes in climate may have on a given system. It is important to state, however, that this is not an exclusive focus, for example, the use of scenarios for forward planning can be applied to both climate and non-climate factors. Moreover, many of the methods can make use of and may even in some way depend on the use of socioeconomic and sociopolitical data. A wide range of statistical data of past changes in economy and society, as well as some projections of future changes, e.g., population change, are available from various national governments and international organizations, for example, the UN and the World Bank.

Scenarios and Scenario Planning

Adapting to climate change and variability essentially means developing plans or strategies that are able to reduce the negative consequences and maximize any positive consequences that may occur. This clearly implies the need to think about the future and how a given system may function or respond, under future conditions of changed climate and non-climate factors. It is not possible, however, to predict the future with certainty and as such there is uncertainty as to what the future may hold. The use of scenarios is one way of dealing with this uncertainty (Rounsevell and Metzger 2010). The value of scenarios as a forward planning tool is to consider the effect that different plausible futures might have for the achievement of business objectives. Scenarios are used in various economic sectors, and perhaps one of the most successful examples of the development and use of scenarios is Royal Dutch Shell Plc, who, through the use of scenarios, were well prepared to respond to the oil price shock of the 1970s (http://www.shell.com/global/future-energy/scenarios.html). Other examples of scenarios are those developed by the International Energy Agency (IEA) (http://www.iea.org/publications/scenariosandprojections/), the World Business Council for Sustainable Development Vision 2050 (http://www.wbcsd.org/vision2050.aspx), and the IPCC Special Report on Emissions Scenarios (SRES) (Nakićenović et al. 2000).

Scenarios may be defined as:

> A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. IPCC (2007)

Scenarios are, thus, not predictions about how the future will turn out, rather plausible possibilities or alternatives that may appear. As such, they serve as an aid to critical thinking when developing strategies or policies to manage or ensure success under different futures. In other words, they provide a framework for asking questions such as: How would our existing strategy work under different future conditions? How might alternative strategies perform under future conditions? Scenarios may be qualitative or quantitative, and often the two are combined, with a qualitative scenario being used to run a quantitative simulation model under the assumptions contained in the qualitative scenario. For example, global climate models are used to generate quantitative scenarios or projections, of how a range of different climate variables may change in the future, based on the assumptions in the SRES qualitative scenarios. Qualitative scenarios are normally accompanied by a "storyline," which provides a narrative description of how a given scenario materializes.

In adaptation planning, the need for developing scenarios will most likely center around developing scenarios in relation to changes in the non-climate factors, for example, how a water supplier would be able to meet a possible rise in water demand of 25 % over the next 25 years. The need for an organization to develop customized climate scenarios (based on climate models) is likely very low, since there are a number of climate scenarios which are available and as such may be used as "off-the-shelf" products, which can then be tailored according to the needs of a given organization. The task then is linking these scenarios which describe different plausible futures to a model of how a given system functions.

Scenarios thus offer a potentially powerful means of supporting adaptation planning, but key to the process is the accurate identification of the key driving forces, how these are then characterized, and the avoidance of bias in thinking about uncertainties (Reed et al. 2013).

Making Use of Climate Information

What Kinds of Climate Information Are There?

Essentially there are two main kinds of climate information of relevance to adaptation planning, derived from observational and modeled data. Observational data are clearly most useful for learning about past and present changes, while modeled data can be used for both learning about the past and also possible future climates. Using these two sources, it is possible to generate information relating to basic changes in climate variables, e.g., surface air temperature, climate indices, and extremes, for example number of days when summer maximum temperature is >25 °C, and to generate projections of possible future climates.

Deciding which kind of climate information to use will depend largely on the time horizon over which a given adaptation strategy may be operative, and the available expertise and resources. If time or planning horizons are relatively short, i.e., the next one or two decades, then adapting to recent climate variability and trends based on observed data may be sufficient. When the lifetime of a given strategy or action has implications for many decades, the performance of adaptation measures should be investigated across a range of climate change scenarios, and modeled climate information will be needed. The focus in this section is on the use of modeled climate information for informing adaptation planning.

Simulating Future Climates

In order to be able to assess future climate risks, it is necessary to have some idea as to how future climate may change, and for this some kind of model is needed. The most sophisticated tool for this is to make use of global climate models (GCMs). It is, however, also possible to simulate or construct future climates using synthetic data (e.g., Lempert and Groves 2010). Performing a climate risk assessment however is not simply about changes in climate, it is also necessary to understand what effect or impact possible changes in climate may have on a given system of interest. In the following sections, some of the main methods and tools that may be used to assess climate risks are described, and the various issues that are associated with their use and application discussed.

What Is a Global Climate Model?

A global climate model (GCM) is a numerical representation of the various processes that take place in the Earth's atmosphere, ocean, cryosphere, and land surface. These models are based on well-established physical laws and observations of physical processes. They simulate, for example, incoming and outgoing radiation, cloud formation and atmospheric and ocean circulation, and they also try to simulate the interaction of these various processes (McGuffie and Henderson-Sellers 2005). GCMs are highly complex and are extremely computationally demanding, making the use of supercomputing a prerequisite. GCMs solve these various processes mathematically at a series of grid points in the atmosphere and ocean, and across the land surface, and as such have both horizontal and vertical resolution. Because of the complexity, GCMs are only currently tractable when run at relatively coarse spatial resolutions, on the order of 100–300 km.

How Is Future Climate Model Information Generated?

Future climate will be largely determined by the concentration of greenhouse gases (GHGs), and aerosols in the atmosphere, and the changes this leads to in the functioning of the Earth system. Future atmospheric concentrations of GHGs and aerosols will be determined in large part by human activities. In order to be able to simulate future climates, it is necessary to make some assumptions about the way in which human activities will be organized in the future, and thus produce plausible scenarios of how concentrations of GHGs and aerosols may develop. The IPCC Special Report on Emissions Scenarios (SRES) (Nakićenović et al. 2000) represents a major activity which has formed the basis for the generation of a large number of climate model simulations. These scenarios make various assumptions about, for example, global human population development, how our economic affairs will be organized, what technologies might be employed, and the fossil fuel intensity of human activities. Recently, a new set of emissions scenarios has been developed by the science community to try and address some of the constraints that use of the SRES scenarios placed on the climate simulations. These new scenarios are called the Representative Concentration Pathways (RCPs) and take a different philosophical approach to that of the SRES (Moss et al. 2010; van Vuuren et al. 2012). Whereas the SRES scenarios assumed a given pathway of socioeconomic development would lead to a particular level of emissions, the RCPs do not. Instead, many different development pathways may be consistent with the level of emissions and thus concentrations of GHGs and aerosols, under the RCP scenarios. A new set of socioeconomic scenarios have been developed, called the shared socioeconomic pathways (SSPs), which may be used in conjunction with the RCPs (O'Neill et al. 2013). Using these emissions or concentration scenarios with global climate models allows future climate projections (or scenarios) to be made, which are conditional upon the assumptions made in a given emissions scenario. In this way, it is possible to obtain quantitative information on the way in which future climate may evolve.

What Kind of Information Can These Models Generate?

Global climate models can be used to generate information for a few months ahead and these are known as seasonal forecasts; for the next decade – these are known as decadal predictions; or for many decades ahead, i.e., 20–100 or more years – these simulations are known as multi-decadal or centennial projections.

To date, most focus in adaptation planning has tended to use multi-decadal projections, which is a function of the relative maturity of this field, and data availability, compared to the seasonal and decadal projections. Seasonal forecasts do have some skill in some parts of the world and are used to help people adapt particularly in less developed nations (Lizumi et al. 2013). Decadal predictions on the other hand also have some skill in predicting certain climate variables and phenomena in certain parts of the world and/or at the global scale. However, these predictions are very much an experimental research area (Meehl et al. 2009). As such, despite their clear appeal in terms of the time horizon, a major amount of progress is needed in this area before they may be suitable for assisting with typical adaptation planning problems (Tollefson 2013).

Deciding which climate model data to use, and for which emissions scenarios, will depend upon the nature of a given adaptation problem, and specifically the associated planning horizon. Clearly, if there is a business decision that needs to be made which is climate sensitive but can be adjusted within a short time period, then using observed data, statistical relationships, or learned experience may be a suitable approach, rather than using modeled data. If, however, there is a business decision whose lifetime will extend over a couple of decades or more, then climate change and climate models will need to be consulted and incorporated into the planning and decision-making process.

Downscaling Global Climate Model Data

Global climate model outputs are not particularly well suited to the kinds of questions related to adaptation planning, owing to their coarse spatial resolution. In order to bring the results of global climate models closer in line with the needs of users, the global climate data may be downscaled (Fowler et al. 2007; Jacob et al. 2013). There are two main approaches to downscaling climate information to the regional level, dynamical and statistical downscaling. Dynamical downscaling proceeds through the use of regional climate models, whereas statistical downscaling can proceed via a range of methods, for example, regression analysis. A precondition for all downscaling, however, is the realistic representation of large-scale circulation patterns from the driving GCMs.

Uncertainty in Climate Model Information and How to Deal with It

Uncertainty in climate model information stems from three main sources: natural or internal variability, model uncertainty, and emissions uncertainty (Hawkins and Sutton 2009). This issue is discussed in more detail in the chapter by Bowyer et al. (2014) in this volume.

The most common way in which uncertainty is quantified is through the use of probability. This can mean specifying a percentile range or possible variation to be expected, through to generating full probability density functions (CCSP 2009; Collins et al. 2012). The way in which uncertainty is quantified is important for the meaning that may be attached to the results of any model or statistical analysis, and thus how this may be used and interpreted in informing the adaptation decision support process.

Given the sources of uncertainty in climate modeling, when generating data that may be used in support of adaptation planning, one would ideally have data available that were generated from multiple different climate models which had each been run multiple times, exploring a very wide range of uncertainty in parameter values. This would also ideally be done for a range of different future emissions or concentration scenarios. Unfortunately, because of the large compute time required to run GCMs, this is not practical at the present time, although progress is being made (Sexton et al. 2012).

What options exist for dealing with this uncertainty? One approach for which suitable data are currently available is to make use of what are known as multi-model ensembles (MME). Because different international climate modeling centers have different models, and structure them in certain ways, combining these simulations into an ensemble is one way in which uncertainty can be explored in the climate modeling. A multi-model ensemble is then a collection of different climate model simulations obtained from a number of different models. Overall, the MME approach does not explore a lot of variation in uncertain process parameters, with typically only a small number of simulations being performed with each model. As such, this approach provides a limited quantification of uncertainty (Stainforth et al. 2007).

An additional way in which uncertainty can be dealt with is to generate what is known as a perturbed physics ensemble (PPE). In this approach, a single climate model is used, in which a large number of model parameter values are varied across their plausible range of values, and the climate model run for each instance. This approach allows the generation of a large number of model versions, each one being part of the ensemble. There are, however, very few examples of such PPEs being generated, owing to the fact that they are so time consuming to generate (Sexton et al. 2012).

Climate Indices and Extremes

Both observed and modeled data can be used to obtain information on changes in climate indices and extremes (defined as any change above a commonly accepted statistical measure of rarity, e.g., 95th or 99th percentile). In relation to adaptation planning, it is often the case that direct experience of, or information related to, extremes can often provide the stimulus for action, in that the direct experience of an extreme weather event creates a so-called window of opportunity (Adger et al. 2007), raising awareness of climate risks, and that action may be needed to address them.

Often, information relating to extremes is presented in the form of indices, e.g., the number of summer days with mean temperature above 25 °C. Information on climate indices and extremes can be used to form either a quantitative or qualitative assessment of what the changes may mean, or indicate, for being able to meet business objectives, either in the past or in the future. It is also worth stating that the use of observed changes in indices and extremes, and any trends in these, can be very powerful in raising awareness of climate change, establishing an evidence base, and helping build a case for the need for adaptation. If the observational data sets can show a clear trend of change, then this can often be sufficient evidence to stimulate adaptation action.

Climate indices contain information relating to changes in climate variables, which may be of relevance to different economic sectors, for example, in the energy sector, the number of cooling degree days and heating degree days is used to help plan and manage energy demand. Indices may be derived or calculated directly from climate observations or modeled data.

Information on changes in extremes is highly in demand particularly for future time periods, from, for example, insurance companies. Figure 2 provides examples of ways in which climate extremes may change under a changed climate. Possible changes in the mean, variability, and shape of climate statistics will lead to different possible changes in the frequency and magnitude of extremes. It should be clear from Fig. 2 that even relatively small changes in the climatology of a given variable can have significant implications for the frequency and magnitude of extreme events (Coumou and Rahmstorf 2012; Rahmstorf and Coumou 2011).

Simulating the Impacts of Climate Change

While the use of climate change data may be of use to develop a broad understanding of possible ways in which a system may be affected under climate change, for example, as part of risk identification, or a preliminary risk screening exercise, the question that really needs to be answered however is: How will a given system be impacted by these changes in climate, and thus the ability of an organization to meet its business objectives? This section provides a discussion of some of the main methods and approaches that can be used to develop an understanding of how a given system functions.

Modeling Climate Impacts

A powerful way of obtaining more detailed information on the way in which a given climate-sensitive system may respond to changes in climate is through the use of environmental modeling tools, which may also be referred to as climate impact models (Challinor et al. 2009). These may be either statistically or physically based models and are used to model various environmental systems and economic sectors, e.g., water, agriculture, forestry, coastal systems, energy, and food. Impact models will typically be driven by climate variables, and other system relevant variables, and may offer some scope for the inclusion of socioeconomic variables. These models may be used to perform sensitivity analyses (discussed in section "Model Sensitivity Analysis"), to try and understand better the way in which a given system responds to climate, and should ideally be able to simulate or integrate the action of adaptation measures or strategies on the system function (Lempert and Groves 2010).

Using impact models can often be a very resource-intensive approach, particularly if a number of climate model simulations, or ensembles, are to be investigated to quantify uncertainty. This need not be the case, however, but careful consideration should be given to the level of detail that is needed in order to answer the kinds of adaptation questions or problems that may exist, and thus using impact models may only be deemed necessary for particularly significant risks.

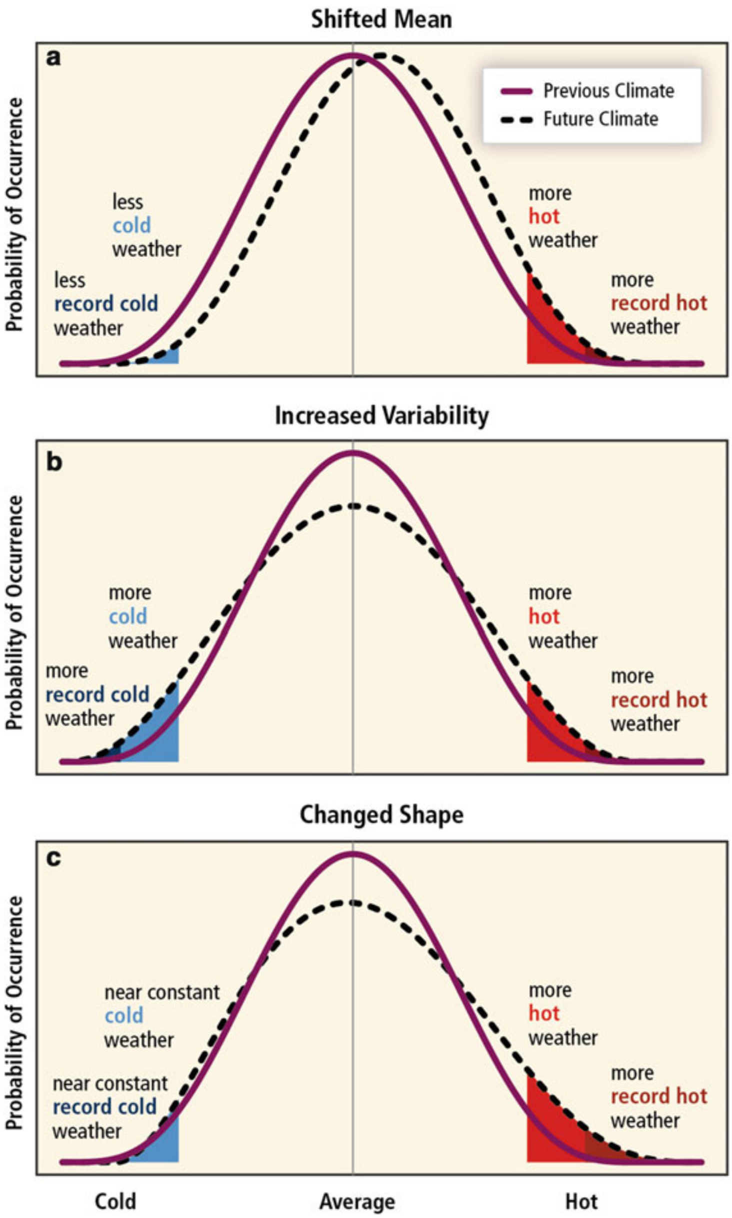

Fig. 2 The effect of changes in temperature distribution on extremes. Different changes in temperature distributions between present and future climate and their effects on extreme values of the distributions: (**a**) effects of a simple shift of the entire distribution toward a warmer climate, (**b**) effects of an increased temperature variability with no shift of the mean, and (**c**) effects of an altered shape of the distribution, in this example an increased asymmetry toward the hotter part of the distribution (*Source*: IPCC (2012))

Model Sensitivity Analysis

A model sensitivity analysis quantifies the way in which the model output responds to variation in the model inputs, and can be used to determine the relative importance of the model parameters in driving variation in the model output (Saltelli et al. 2000). Using a given impact model, sensitivity experiments can be conducted where a wide range of known or expected variation in the relevant climate and non-climate parameters is explored and then analyzed to see how the given system (model) responds. This could be done with modeled climate data, or a less resource-intensive approach would be to generate synthetic climate data. Sensitivity analysis can be used to help identify those factors which are most important to control or which have most influence on the functioning of a system, and thus can be very instructive in the search for adaptation measures or strategies. Moreover, it may be possible to explore the efficacy of potential adaptation measures across a large range of possible futures, using a sensitivity analysis. This would serve to highlight where, or under what conditions, a given adaptation measure may be suboptimal or less robust. This kind of information is potentially very informative in the process of selecting adaptation measures.

Model sensitivity analysis provides a powerful means of learning about the functioning of a system and is less resource-intensive than generating an ensemble of impacts based on a climate model ensemble. The results of a model sensitivity analysis can also be used to generate what are known as impact response surfaces.

Climate Impact Response Surfaces

Model sensitivity analyses can lead to the identification of a set of model parameters which are most influential in driving the system response. Using this approach, it may be possible to generate a functional relationship between a small set of model parameters and the system response (Fronzek et al. 2010). In so doing, it is possible to generate what is known as a climate impact response surface, which represents this functional relationship. This system response could be a threshold value of high relevance to a given business objective. For example, it may be necessary to have a certain water level in a river to allow transportation of manufactured goods or river water temperatures which may place a constraint on the availability of cooling water for power stations (van Vliet et al. 2012). An impact response surface could be used to investigate how often in the future this threshold level would be exceeded, and thus help support decisions in relation to developing adaptation measures. An example of an impact response surface is shown in Fig. 3.

This method provides a rapid, quickly updateable and reusable tool for understanding the effects of changes in climate on the system response. As new climate data sets become available, they can simply be plotted over the existing surface (assuming no change in the functional relationship), and analyze if new information leads to any change in the exceedance of a valued threshold. This attractive feature of reusability and being easily updateable as new climate information becomes available or, as business objectives change, means that this approach

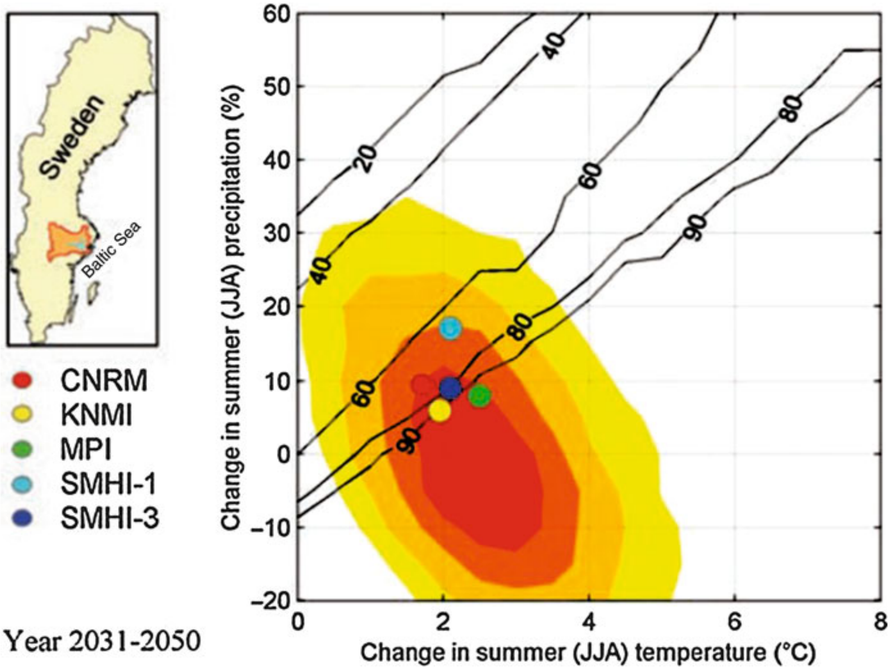

Fig. 3 An example impact response surface for Lake Mälaren in Sweden. Diagonal *black lines* are the likelihood in percent of summer water level being below the target operating threshold for a consecutive period of 50 days for the change in summer temperature and precipitation. Climate projections for the time period 2031–2050 are shown as probability density plots in the colored area, which encloses approximately 90 % of all projected outcomes. The *colored dots* are projections from regional climate models (*Source*: van der Linden and Mitchell (2009))

may represent a good return on any investment made to develop such tools, and is easily incorporated and used as part of an iterative review process of climate risk management.

This approach is most suitable for systems whose response is driven very strongly by a few climate variables, e.g., in the water and forestry sectors (Prudhomme et al. 2010; McDaniels et al. 2012). Also, the accuracy of these surfaces compared to a full modeling approach should be assessed and reported. Also consideration of the uncertainty in the modeled response itself needs to be considered in the sense that a different impact model may give a different surface. These response surfaces serve to highlight visually when business objectives may be vulnerable, or alternatively, where a particular risk may become worth exploiting. Challenges arise when this response surface cannot be defined with less than four parameters, because one of the big attractions of response surfaces is the rapid assessment that visualization provides. With more than three parameters, visualization becomes difficult.

Decision Making Under Uncertainty

The foregoing discussion has focused on a range of methods and tools that may be applied at the risk assessment stage of the risk management process, in order to establish a basis upon which the significance of any risks can be assessed. Any risks which are deemed to need treating will then require an adaptation strategy and will need to appropriately consider the issue of uncertainty.

Because of the various sources of uncertainty in adaptation decision making, it is simply not possible to accurately predict what the future world will be or look like. The only credible way of acknowledging and dealing with this uncertainty is to explore as wide a range of different possible futures as possible. The task then is to endeavor to understand what this may mean for the functioning of a given system, and the effect it may have on an organization being able to successfully meet its business objectives, and thus planning and implementing adaptation strategies. Moreover, it is also a fact that developing an effective adaptation strategy will also need the approval of a range of different stakeholders, who will have different values and priorities. As such, developing an adaptation strategy is not simply about having an evidence base and information but obtaining stakeholder engagement and buy-in. This adds another layer of uncertainty to the process, such that it may be said that adaptation takes place under conditions of deep uncertainty. Lempert et al. (2004) characterize deep uncertainty as being the situation where "decision makers do not know or cannot agree on (1) the system models, (2) the prior probability distributions for inputs to the system model(s), and their interdependencies, and/or (3) the value systems used to rank alternatives."

Given this reality, an organization is faced with the question of how best to make decisions in these circumstances. Should an organization seek to predict the future and strive to optimize an adaptation strategy around what is determined to be the "most likely" future? Or, instead, should an organization acknowledge that pursuing an optimizing approach is highly vulnerable to futures different from what was considered to be most likely, and accordingly seek robust adaptation strategies that perform reasonably well across a range of different possible futures?

This section discusses the implications of deep uncertainty for developing adaptation strategies, whether to optimize, or hedge and seek robust decisions (Weaver et al. 2013). In addition, a discussion of the robust decision-making framework is provided.

To Hedge or Not to Hedge: That Is the Question

In the context of using climate information to support adaptation planning and decision making, there are two alternative decision frameworks that are applied, a predict-then-act framework and a robust decision making (RDM) framework (Weaver et al. 2013):

1. **Predict-then-act**: this has been the most commonly adopted framework, under which optimal strategies are sought which seek to maximize the expected utility of a given adaptation strategy. This framework relies on the ability to predict the "most likely" future (Lempert et al. 2004). To determine the "most likely" future requires that probabilities are assigned to model predictions.
2. **Robust decision making**: this framework has more recently gained traction in the adaptation arena (Lempert et al. 2006; Lempert and Groves 2010; Kunreuther et al. 2013). This framework seeks to minimize the regret associated with a given adaptation strategy, by evaluating a number of different strategies and selecting that strategy which performs relatively well compared to the alternatives, across a large range of possible futures. This relative performance measure is the robustness criterion and, because it does not seek to provide an optimal outcome under one "most likely" future, provides a hedge against uncertain futures. The performance criterion is the level of robustness offered by a given strategy, in the sense that it fails to meet its objectives on fewer occasions, or is less sensitive to uncertainties, than the alternative strategies.

Deciding which of these two frameworks is most suitable for application essentially comes down to how seriously a given adaptation strategy is, or may be afflicted by, the issue of deep uncertainty. Clearly, deep uncertainty will be more or less important depending on the decision context and nature of the uncertainty associated with a given strategy. If the strategy does not affect external stakeholders, has a short decision lifetime, has flexibility, and/or is a no, or low regret, option, then the predict-then-act framework may be suitably applied. If, however, the strategy has a long decision lifetime, has limited flexibility, and/or involves external stakeholders, then an optimal strategy designed under the predict-then-act framework may be too vulnerable or risky in the face of futures different from what was considered most likely when the decision was made. In addition, pursuing a predict-then-act approach will also be more vulnerable to the occurrence of surprises. In these cases, a robust decision-making framework is likely to be more suitable. It is worth stating that there may also be pragmatic reasons for adopting one or the other decision framework.

Robust Decision Making

Under the robust decision-making framework, one accepts that there are multiple plausible futures, and seeks to explore how a given business objective may fare under a range of different futures (Weaver et al. 2013). The approach starts first with the candidate adaptation strategies and then uses a modeling framework which samples a range of uncertainty in the main decision relevant system driving variables to generate a large number of scenarios. The question then asked is, under

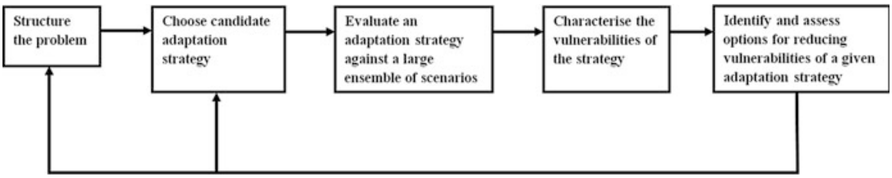

Fig. 4 Steps involved in a robust decision-making analysis (*Source*: Adapted from Lempert and Groves (2010). In operation, the RDM method combines steps 3 and 5 of the risk management process (risk analysis and adaptation option appraisal))

what future conditions would a particular adaptation strategy fail to meet its business objectives, as represented by some performance criterion (Lempert and Groves 2010)? The RDM approach is an iterative method which tests out different candidate adaptation strategies, seeking to characterize the vulnerabilities associated with each and using this information to inform and identify alternative strategies that may be more robust. The RDM approach is summarized schematically in Fig. 4.

As originally conceived, RDM was a quantitative computational model approach (Lempert et al. 2006) and as such can require a lot of resources. However, the principles involved in the approach can be equally well be applied to qualitative conceptual models of how a given system functions, which provides a much less resource-intensive approach, as recently demonstrated by McDaniels et al. (2012).

Conclusion

Framing adaptation as an issue of climate risk management provides a range of attractive features which should ensure adaptation can be understood and acted upon within existing management structures. A range of different issues are involved at the different stages and these need proper consideration in adaptation planning. There are several different methods and tools available that may be applied to help carry out a risk assessment, in order to generate an evidence based upon which the significance of climate risks can be assessed, and the necessity of treating them analyzed. Key to the risk assessment stage is having or developing a causal model which explains the way in which changes in climate can lead to impacts on the activities of a given organization and thus understanding how a given system functions. This understanding is central to the search for effective adaptation strategies.

Developing adaptation strategies also involves a range of different issues, not the least of which is how best to develop a strategy in the face of deep uncertainty. The two main approaches of predict-then-act and robust decision making can equally well be justified in practice, depending on the exact nature of the uncertainty associated with a given adaptation problem and strategy. The key issue in thinking about adaptation and making decisions is that it is an analytical process which needs to draw on a wide range of different expertise and stakeholder involvement. At different stages of the adaptation process, different information, skills, and approaches are needed. A risk management framework provides a well-established method which can accommodate all these different aspects.

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Adapting Nature-Based Seasonal Activities in Quebec (Canada) to Climate Change

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Abstract

This chapter attempts to illustrate the socioeconomic implications of climate change on alpine and cross-country skiing, golf, snowmobiling, and nature parks at a local and regional level. A transdisciplinary approach is used to create a framework for adaptation responses relevant to the Laurentian and the Eastern Townships regions. Participatory Action Research (PAR) process through social analysis tools and techniques www.sas2.net (SAS^2) leads to better comprehension of perceived changes and business realities, recognition of climate risks, and identification of actions to manage CC-related risk. This process establishes an environment for dialogue, transparency, and progressive awareness about spatial and temporal repercussions for subsectors and regions. Consequently, growing concerns relate to the need to plan adaptation solutions by combining them to other significant business challenges. Interests now focus on feasible adaptation responses to the current effects and projected climate, along with its interrelated socioeconomic risks. The main aim here is to outline a more personalized approach by encouraging business-driven solutions, in such a manner that it can be used as a model to other tourism regions in the province of Quebec.

Keywords

Adaptation process • Climate change • Collaborative Participatory Action Research (PAR) • Regional tourism regions Businesses • Transdisciplinary • Quebec • Canada

Introduction

A 2011 report by the National Round Table on the Environment and the Economy (NRTEE) suggests that climate change (CC) could cost Canada roughly CAN$5 billion per year by 2020 and from $21 billion to $43 billion per year by mid-century. As a highly climate-dependent industry, tourism will be significantly affected by global warming (Becken and Hay 2012). One key way to reduce the impact on operating costs is adaptation (REDD 2011).

Even though Northeast America is not considered a CC vulnerability hotspot for tourism, other scientific fields are gathering significant evidence of environmental transformation across Canada and Quebec (Allard and Lemay 2012; Ouranos 2010a). Some of these changes will have important impacts on seasonal, nature-based recreation and sports tourism (MDDEP 2012; Simpson et al. 2008; Scott et al. 2007a; Scott and Jones 2007).

Climate change (e.g., the changing hydrological cycle) and related physical and environmental effects (e.g., regional water and snow scarcity) trigger cascading repercussions on local businesses, destinations, and regions (REDD 2011). As provincial supply extends over the entire southern portion of Quebec, opportunities and risks will arise from climate variability and conditions that are extreme in terms of magnitude, frequency, and intensity, particularly in major economic regions such as *the Eastern Townships and Laurentian regions, that offer golf, alpine, and cross-country skiing, snowmobile trails, and parks.*

The nature-based and sports activities provided by tourist operations play a crucial role in regional and local economies (Ministère du Tourisme du Québec 2012, 2009; CQRHT 2010; Scott et al. 2008; ASSQ et al. 2008). CC can thus be considered a threat, and tourism managers and operators should plan accordingly to reduce their exposure (NRTEE 2012).

Uncertainty about the current and future climate conditions will alter visitation and participation rates (Scott et al. 2011). Predicted CC scenarios, such as changes in precipitation patterns and temperatures, and the increased occurrence of natural hazards such as heavy rains and intense storms, flooding, as well as indirect consequences of biodiversity loss and vector-borne diseases will have major implications for tourism (Scott et al. 2002; Bourque and Simonet 2008).

In the past years, severe meteorological and hydrological phenomena have affected outdoor tourism operations in Quebec and tested decision-making and response mechanisms. Highly unpredictable and variable conditions (i.e., heat waves) in Northeastern Canada led to early closure of ski resorts, with an 8 % decrease in attendance over the previous year (Archambault and Germain 2012). A small consolation for Quebec, the National Ski Areas Association (NSAA and RRC Associates 2012) found that the 2011–2012 season ended in a major frequency drop, making it the worst in 20 years, with visits to Northeast USA down to 20 %.

Interviews conducted by analysts from the Transat Chair in Tourism (University of Quebec at Montreal) with ski resort managers show a marked change in attitude: for example, in the last decade most operators used different ad hoc adaptation strategies that focused primarily on marketing and snowmaking, despite limitations and sustainability of the last approach. As the awareness of the long-term nature of CC grew, ski resorts have developed their own adaptation strategies that tend to focus on technology, activity diversification, and resort partnerships (alliances) as a means of coping with changing snow conditions (Archambault and Germain 2012).

The changing climate presents opportunities for industry transformation. As pointed out by the NRTEE, *Just as businesses must readily manage financial and regulatory uncertainty, they must also understand the risks and potential opportunities presented by a changing climate and position themselves to respond appropriately.*

Recent circumstances call for new sustainable operational and management skills (McBean 2012; IPCC 2012; Ministère du Tourisme du Québec 2012 – PACC 2013–2020). Despite the fact that environmental impacts can affect the value and supply chain and natural assets (McBean 2012; NRTEE 2012; Gössling et al. 2012; Felmate et al. 2012; Vescovi et al. 2009; Scott and Jones 2006a, 2007), the tourism industry still does not fully grasp the need to adapt (Weaver 2011; see Bramwell and Lane 2007).

In many cases, tourism coverage in CC literature is virtually nonexistent or is discussed too generally to help key players develop adaptation strategies or measures (Scott et al. 2012). Knowledge of appropriate adaptation mechanisms for specific outdoor recreation and tourism sectors is very limited (Agrawala 2007; Scott and McBoyle 2007; Pelling 2011) or else restricted to specific regions such as Quebec. The best way to involve partners in adaptation strategies is to create a partnership between local and regional associations, universities, and different levels of the government, thereby combining tourism expertise with the latest climate science knowledge.

This chapter presents an integrated collaborative approach to adaptation. Ouranos – a consortium on regional climatology and CC adaptation – and industry associations from the private sector joined forces in a program (including collaborative Participatory Action Research [PAR]) that aims to initiate dialogue on climate risk and create a flexible, realistic framework for local and regional adaptation responses.

This exploratory study is original in many ways. It used a five-step plan to achieve three research objectives: (1) scenarios/estimates, (2) workshops, (3) questionnaire, (4) benchmarking, and (5) brainstorm sessions. The article focuses on steps 2 and 5 of the study. Results from each step informed subsequent steps. The workshops were based on the modeling results. The strategic orientations of the workshops provided a basis for the questionnaires, helped target adaptation strategies and best practices outside Quebec, and validated individual, local initiatives. Results from the first four steps were reported at two regional brainstorming sessions, where discussion centered on critical strategic orientations for adaptation to CC and the future of this project.

The following chapter will discuss the process analysis and research project management, the stakeholder interaction, the workshop techniques and methods used, the quality and relevance of results, and the benefits of collaborative research in decision making.

In conclusion, recommendations are highlighted for future projects using an action-based learning system to address climate risk and adaptation responses in a transdisciplinary research context. It is expected that this type of collective brainstorming will generate adaptation solutions that will lead to the creation of interactive documents through ongoing, collaborative authorship.

Literature Review

Climate: Tourism

Despite increased global awareness of the significant impact of climate change (CC) on tourism, practical and effective responses remain limited (Becken and Hay 2012, p. 1; Berrang-Ford et al. 2011). In the last decades, research to better understand CC and its implications has intensified. Investigations started as early as the 1960s through weather-/climate-related and tourism-/recreation-related articles in research journals and lasted throughout the 1970s (Scott et al. 2005a). In 1970 Mandauer (as cited in Scott et al. 2012, p. 60) noted that the effects of weather on tourist regions and the extent of weather-related effects on tourists were still largely unknown.

Today, some experts feel that, while research publications on climate change or climate/weather in the context of tourism display a more mature approach (Scott et al. 2005a), the research field is not sufficiently developed (Fisher 2007). Knowledge advancement is weakened by sparse weather and climate data and a geographical research imbalance largely dominated by northern countries (Fisher 2007). According to Kajàn and Saarinen (2013) despite more prolific output in the late 1990s, these observations still hold true today.

Climate Trends and Environmental Change

Changes have been observed both in mean conditions and also in the frequency and intensity of weather and climate patterns across the province (Ouranos 2010a; Allard and Lemay 2012). In southern Quebec, recent trends show decreased snowfall patterns especially during the freeze-up cycle (Duguay et al. 2006; Brown 2010). Estimates show that between 1981 and 2004, the summer season has lengthened by an average of 0.8 days per year (Yagouti et al. 2006; Julien and Sobrino 2009). With average temperatures above the climate normals of 1961–1990, the last 12 years have been the warmest on record (Ouranos 2010a; Allard and Lemay 2012; WMO 2012).

Further alteration of climate conditions could intensify the hydrological cycle, as well as drought, snow, and ice distribution patterns (Prowse et al. 2007; Allard and Lemay 2012). More frequent low-pressure systems, decreased ice cover duration, soil thawing, and rising mean that sea levels are already affecting southern Quebec. These physical conditions weaken infrastructures and the built environment (Bleau 2012; Allard et al. 2008), biodiversity, ecosystems (Berteaux et al. 2010), and communities (Savard 2010).

Impact Assessments on Recreation and Sports Tourism

Numerous studies have evaluated the risks that climate change poses to tourism and outdoor recreation in environments similar to those in Quebec (New England – Dawson and Scott 2007; Scott et al. 2008; Dawson et al. 2009; Ontario – Scott and Jones 2006a, b; Jones and Scott 2006a; McBoyle et al. 2007; Brown and Hunt 2007; Finland – Sienvanen et al. 2005).

In Canada and the United States, the most vulnerable sectors are the snow-dependent ones such as alpine skiing (Scott et al. 2003, 2008; Dawson and Scott 2007; Hamilton et al. 2007; Shih et al. 2009), snowmobiling, and cross-country skiing (McBoyle et al. 2007; Scott et al. 2011; Blangy et al. 2011). However, CC scenarios have shown increased participation in various peak and shoulder season activities, events, and festivals (Scott et al. 2005b), visits to provincial and national parks (Richardson and Loomis 2005; Scott et al. 2007b; Jones and Scott 2006a, b), and golf (Scott and Jones 2006a, b; Scott et al. 2011), that would generate economic benefits. Still, further studies are needed to ascertain how the tourism industry must change in order to reduce the risks and sustainably increase the benefits (Dawson and Scott 2010).

Quebec has made little progress in understanding how CC will affect the socioeconomics of regional recreation and sports tourism. While the impact remains hard to quantify (Scott et al. 2005a), two studies addressing the relationship between outdoor activities (alpine skiing and golf) and future climate scenarios revealed preliminary results (Singh and Bryant 2006; Scott et al. 2007a). Although incomplete, these studies clearly identified the risks of snow dependency for ski resorts and the benefits for golf courses. Further investigation is required as neither study assessed the direct relationship between climate, recreation, and the economic impacts on regional tourism.

As previously mentioned, research has documented the current and anticipated effects of CC on seasonal sport and outdoor recreation (Abegg et al. 2007; Moen and Fredman 2007; Scott et al. 2009), also has highlighted the importance of adaptation and mitigation strategies (Agrawala 2007; Scott et al. 2007a, 2011; Dawson and Scott 2010), and identified some obstacles to implementation (Lemieux and Scott 2011). However, further multidisciplinary research is needed to assess vulnerabilities, inform tourism leaders – businesses, nongovernment and government bodies, and academic institutions – of the costs and advantages of adaptation, and provide them with the tools and insight to make targeted decisions on adaptive responses to climate change.

Adaptation

Adaptation to climate change refers to an action-oriented process and the resulting strategies and initiatives (Smit and Pilifosova 2001). It is defined by the Intergovernmental Panel on Climate Change (IPCC) as the “[a]djustment in human or natural systems to actual or expected climate change or their effects in order to moderate harm or exploit beneficial opportunities” (IPCC 2007), and by the United Nations Development Program (UNDP) as “a process by which strategies to moderate, cope with and take advantage of the consequences of climatic changes are enhanced, developed, and implemented” (UNDP 2005). CC means not only protecting against the negative impacts of climate change but also taking advantage of any socioeconomic benefits it may bring (EEA 2013, p. 14). Ouranos (2010b) adds that adaptation affects all levels of decision making (individual, local, regional, national, and international) and requires a global and integrated approach, as issues often intersect and extend beyond administrative and territorial boundaries.

Frameworks and Adaptation Planning

According to Scott et al. (2012), tourism industry adaptation research and practices lag 5–7 years behind other economic driver sectors. Several countries have conducted or are currently conducting large-scale research projects on the adaptation needs of sustainable tourism. Yet, according to a OECD/UNEP 2011 poll, only 2 out of the 18 countries surveyed had a tourism adaptation policy either at the planning or implementation stage (Scott et al. 2012).

Several of the countries studied were committed to creating knowledge and awareness among tourism players (OECD/UNEP 2011). However, tourism strategies with concrete climate adaptation measures are still either rare or nonexistent (Ministère du Tourisme du Québec 2012; Felmate and Thistlethwaite 2012). As pointed out by Berrang-Ford et al. (2011), despite studies on the adaptation of tourism practices to climate variability, most publications merely describe human intentions and environmental vulnerabilities with no tangible actions from stakeholders (Becken and Hay 2012). Apparently, the private sector in most countries is not yet fully integrated into adaptation policy processes (EEA 2013, p. 8) even though various impacts and vulnerabilities emerge at local and regional levels (Adger et al. 2007; Frankhauser 2009; Swart et al. 2009).

As stated in the European Environment Agency's (EEA) latest report from 2013, this is because national frameworks and research activities often fail to prioritize economic- and business-related topics. However, practical case studies on Canadian and US businesses show that they recognize the benefits of acting now to prepare for future climate realities. For instance, Whistler Blackcomb Holdings Inc. has its own mitigation/adaptation strategy. The benefits of such strategies consist in protecting value, reducing existing weather- and climate-related risks, and creating value by strengthening market position (NRTEE 2012, p. 6). Still, information on the obstacles to implementing private-sector measures and initiatives at the local or regional level is limited, as national plans and strategies often fail to relate to the needs of these organizations.

So far, it is acknowledged that Canadian companies have made little effort to implement strategies and measures to effectively manage the increasing climate risk (REDD 2011; NRTEE 2012). Given that new published tourism development frameworks (2012) at both federal and provincial levels have left out adaptation to CC, the adaptation actions taken by tourism operators are mostly reactive or voluntary. However, consistency across ministries and agencies is now supported by the provincial Ministry of Sustainable Development, Environment, wildlife and Parks through the 2013–2020 Government Strategy for Climate Change Adaptation.

Introducing a Collaborative Approach

Studies on tourism and CC adaptation recommend tourism stakeholders to work hard to identify relevant adaptation strategies with respect to activities, products, or destinations (Wilson 2006; Nicholls and Holecek 2008). Stakeholder discussions will be more effective if supported by the best available climate change data and industry impact scenarios (Wall and Marzall 2006). Other researchers also suggest that adaptation planning must be an ongoing process and continue at different levels, including at the territorial level (Wilson 2006; Scott and McBoyle. 2007).

In tourism, the process can be beneficial whether it takes place at the subsector level (i.e., skiing) or at the destination level (i.e., Mont-Tremblant). Integrating adaptation strategies into decision-making mechanisms and capacity building is a highly variable and complex process, given that the sector includes many stakeholders, diverse business models, territories, and resource needs (Scott 2006; Scott et al. 2009; EEA 2013, p. 19). For example, adaptation strategies for a golf course may involve water use restrictions, while for a four-season resort, these may be associated with energy, water, insurance costs, or competitiveness.

Dubois and Ceron (2006) have pointed out that once potential climate change impacts are known, it is easier and more efficient to focus on adaptation strategies. Ongoing discussions with stakeholder groups at the regional and sectoral levels may provide more valuable information of how businesses can adjust and what incentives are required for feasible implementation (Simpson et al. 2008). According to the NRTEE, decision makers – from operational managers to directors – should broaden their outlook by considering climate risk. Ideally, working in partnership will provide for increased knowledge, data access, sharing best practices, implementing adaptive measures, and becoming advocates for policy change.

In this sense, a holistic approach, such as collaborative Participatory Action Research (PAR), is required to help subsectors adapt. PAR is built on mobilization and knowledge transfer and exchange, with all players, including the researchers, sharing responsibility for gathering knowledge and committing to community involvement (Anadon 2007). The challenge of PAR is for all players – subjects and researchers alike – to make flexible use of the tools involved in a way that structures the approach within an analysis context that is still undefined (Dubost and Lévy 2003; Blangy 2014). Chevalier and Buckles (2013) participatory social system analysis techniques (SAS^2) provide such a methodological framework. A number of the techniques from their set of 50 can be applied to tourism (Chevalier et al. 2011; Blangy et al. 2010). An action-based learning system allows partnerships to be created and skills to be developed in order to discuss issues and strategies and integrate techniques. Over time, participants are empowered to engage in further dialogue and develop sector-based competencies (Chevalier and Buckles 2013).

Methods

The approach used in this study is original in many respects. Its success is due to the following factors:

- An ambitious and clearly defined specifications and program
- Intellectual and financial input from the private sector, including strong expectations regarding the deliverables for each step of the project

- Two pilot regions representing Quebec tourism in terms of products, visitation, and geographic location
- The involvement of expertise for all five steps of the project: scientists from different disciplines (socio-anthropology, climate science, and tourism), consultants, regional tourism managers, local and provincial government representatives, and sectoral associations
- The emphasis on participatory workshops and brainstorming sessions involving experts in workshop design and facilitation
- A five-step project plan (scenarios and estimates, workshops, questionnaires, benchmarking, brainstorming sessions) that allowed the group to learn, share, and jointly produce knowledge

Study Scope and Objectives

The purpose of this study was to provide participants with a *greater understanding of* the climate issue by using not only climate and tourism scenarios but also peer-reviewed *adaptation case studies* and overseas research projects. Also, the aim was to learn about *the climate perceptions and seasonal business realities of subsectors* regarding the more recent climate conditions. Finally, *an adaptation dialogue* was engaged based on learning and transparent discussions by sharing experiences and subsector and regional transformations, expected to take place by 2020–2050 (cf. Table 1).

The goal of the above-mentioned process was to enable participants to recognize the risks of climate change (CC) and identify regional and local adaptation initiatives by making use of current scientific information. Raising awareness of CC is expected to improve how public and private tourism stakeholders adapt to new realities and provide the first major, multilevel recommendations for Quebec's tourism industry.

Table 1 The three study objectives and the five steps to move forward

Three objectives	Five steps
Assess potential socioeconomic impacts of CC	1. Evaluate current and future impacts on tourism and the economy, using climate scenarios and daily attendance (1998–2008) data
Assess climate perceptions within pilot regions and sectors, and identify relevant adaptation strategies	2. Organize five participatory workshops to assess CC perceptions of impacts/risks and probability of recurrence
	3. Conduct online questionnaires and phone interviews to validate workshop results (154 managers across all 5 outdoor activities)
	4. Benchmarking: identify best practices and adaptation strategies for Quebec
List potential adaptation measures and formulate recommendations for the tourism industry	5. Organize two regional (PAR) brainstorming sessions with the Laurentian and Eastern Townships representatives

To achieve these goals, a working group met in 2010, consisting of the Transat Chair in Tourism of University of Quebec at Montreal (ESG UQAM), as well as 19 businesses from the Quebec tourism industry organized into sectoral associations, the Ouranos consortium, and the Research Chair in Global Change and Tourism at the University of Waterloo.

The Chair in Tourism initiated and coordinated the project. For many years the Chair has been gathering intelligence on the Quebec tourism industry. Ouranos, the consortium on regional climatology and adaptation to CC, played an important role in the development of this project assessment by providing output from the Canadian Regional Climate Model as well as climate-related expertise to the tourism experts. This information is an essential building block for the assessment and development of local and regional adaptation strategies.

Cooperation agreements were signed by the Chair and several sectoral associations (golf, camping, cross-country and alpine skiing, snowmobiling, and nature parks), who together funded the research along with the Natural Resource Canada.

Two pilot regions, the Laurentian and the Eastern Townships, were selected for their diversified and mature seasonal products. This allowed us to investigate the complexity and severity of the related socioeconomic risks and opportunities to unfavorable weather and climate conditions and to determine the extent of CC impacts on the above-mentioned nature-based and recreation sectors.

The Laurentian tourism region covers 20,559 km^2 and is located in southwestern Quebec. The region is strongly influenced by its geography and settlement history. From a demand perspective, the Laurentian region has the third highest visitation levels in Quebec, with 2.9 million tourists in 2008 (Montreal and Quebec City rank first and second in terms of total visitors). The Eastern Townships tourism region covers 10,200 km^2 (about 0.6 % of the province) and is located in southern Quebec, adjacent to the US border (Vermont). With 2.6 million tourists per year, the Eastern Townships is the fourth most visited tourism region in Quebec (Ministère du Tourisme du Québec 2009).

The following focuses on steps 2 and 5 of the project, in which researchers engaged in ongoing dialogue, shared knowledge, and built joint strategies with businesses (Fig. 1, Table 1).

Participatory Workshops

To implement a participatory approach, socio-anthropologist Jacques Chevalier from Carleton University (Ottawa), an expert on Participatory Action Research, was called upon (www.participatoryactionresearch.net). The originality of his approach lies in the flexible use of a wide variety of group facilitation techniques combined with fact-based thinking and analytical methods, so that the process satisfies the needs and working methods of all stakeholders.

Although the sectoral and regional workshops had different yet complementary designs, they yielded comparable results. The workshop structure was based on

Fig. 1 The five steps process of the project

a progression that participants could readily understand: *What we know; What we can expect; What we are already doing; What we could do together*. Participants at the sectoral workshops explored in detail what factors hindered or promoted the development of snowmobiling and cross-country skiing. They worked on sector-specific strategic orientations in the areas of communication, diversification, trail access, snowmaking, and club and ski center organization. Participants at the regional workshops shared their perspectives on CC and discussed the likelihood that such changes will recur.

The workshop exercises were supported by visual aids (radar and Cartesian graphs), analysis software, stories, and a combination of plenary and small group sessions (Table 2). These activities provided participants with an opportunity to analyze extreme weather events and their perceptions of CC, share their knowledge, and study both their individual strategies and the means of developing future collective strategies.

Participants compared their current status with their target status by using the evaluation wheel or radar graph. Each spoke of the wheel represented one of the strategic orientations and conferred a score of 0–5. The gap between the current and target statuses indicated by the wheel-enabled participants to assess the work required to develop new strategies and put them into action. The discussion focused on *Where we are now* and *Where do we want to go from here* and how collective strategies can be improved.

Three regional and two sectoral workshops were organized over the 3-month off-season between March and May 2011. Each workshop involved between 10 and 16 participants, for a total of about 100 participants. Those participants involved in

Table 2 SAS^2 workshop techniques used and relating to examples from Figs. 2 to 4

Telling the story	Timeline: tell a story of gradual CC and extreme weather events from the past
	Cartesian graph: understand CC perceptions through probability and magnitude of impact (+/−) on seasonal products
Monitoring and project evaluation	The Socratic wheel: define the criteria, indicators, and information needed to measure current, ongoing, and expected progress in achieving project results
	The Roman Carousel/projections: visualize what can be expected if current trends continue (climate phenomenon perceptions and probabilities)
Diagnostics and problem solving	Force fields: identify ways to act on key contributing and mitigating factors
	Validation: discuss additional evidence and the stakeholder involvement required to better understand the problem and make plans
Working together	Negotiation fair: assess what stakeholders can expect from each other and negotiate those expectations, then plan concrete actions to meet those expectation, and resolve key problems

the brainstorming sessions were leaders – presidents of sectoral, regional, or local associations – along with provincial government bodies that promote local economic development and support entrepreneurship, managers, tour operators, and so on.

At the very first regional workshop, cross-country skiing and snowmobiling associations (which are especially affected by CC) asked that the first workshops be devoted to their sectors. Less affected subsectors – golf, parks, and camping – were prepared to wait for their turn. Participants received an illustrated report of the workshop content, complete with pictures and graphs showing the processes, techniques, and validated results (Blangy et al. 2011).

Regional Brainstorming Sessions

After this fourth benchmarking step, results were summarized and compiled into reports, fact sheets, and PowerPoint presentations intended for all stakeholders. This CC information package was used at the regional sessions that comprised the final phase of the study and served as a basis for elaborating new tools for the industry: video clips on such topics as climate system, impacts, extremes, and adaptation, analyses by the Tourism Intelligence Network, case studies, and brochures for sectoral associations.

At this stage of the adaptation process, the goal of pursuing the collaborative approach with local and regional actors was to deepen insights on adaptation at the regional level (i.e., the Laurentian and the Eastern Townships). Both sessions focused on transferring newly acquired information to stakeholders from earlier phases. The workshops and questionnaires revealed that it was imperative to bring stakeholder knowledge up to date and create a common basis for discussion, so an information package was created and distributed to participants from both pilot regions. These included commonly used terminology from adaptation and climate sciences and two summary tables (see Bleau et al. (2012) and Tables 25 and 26). The latter showed the impacts and consequences – both positive and negative – of CC on winter and summer practices collected from workshops (Blangy et al. 2011), web questionnaires of 154 managers, and phone interviews.

This information package required several weeks of work because of the large amount of information collected during earlier steps, as well as the tools and methods used. In addition, it was agreed that the methodology should be flexible to match ground reality. These sessions led actors to define adaptation actions for their territories and determine who would implement them. At this stage, concepts of flexibility and time scales (short, medium, long) were important to continue a dynamic process of gradual adaptation. These sessions promoted awareness building and problem solving rather than firm decision making.

Brainstorming session participants were asked to select two strategic orientations (themes) from among the seven orientations that were ranked in order of importance in the workshops and to outline possible regional actions. This exercise was followed by negotiation fairs, at which participants discussed both their needs and the services they could offer. The outcome of this process was a set of recommendations and possible specific actions involving major future actors.

The above approach generated a regional vision around the two selected axes and helped identify obstacles and strengths for each region, while creating the first set of broad recommendations for the tourism industry. However, the brainstorming sessions did not reflect the full territorial offer because major actors were missing.

Finding

Results provided multiple insights, both tangible and intangible, regarding the data and participatory processes in general. Here the focus is solely on the workshop and brainstorming session results.

Process Outcomes

This project was primarily successful because of the participatory approach, the care taken to design and facilitate workshops and report the data.

Workshop design is crucial to the success of the participatory process. The workshop facilitator also plays an important role, provided that he/she has the tools to foster dialogue. A similar workshop design made it possible to compare and confirm data trends. From the three regional workshops, five identical strategic orientations emerged, while two other orientations revealed the different regions' climatic and geographical differences.

The workshops' visual aids saved a great deal of time and energy. In a single day, the sectoral groups made a diagnosis, identified factors that hinder or promote their activities, developed adaptation scenarios, and wrote a draft strategic decision-making plan.

The social analysis tools and techniques developed by Chevalier (Chevalier et al. 2011) helped participants to set forth perceived environmental changes and business realities, recognize climate risks, and identify actions to manage CC-related risk. The workshops helped clarify adverse consequences for each sector, created a sense of ownership, gave people a chance to share knowledge and build bridges, and developed links between communities and operators so they could work at the regional level.

Participants reportedly enjoyed the workshops and felt they created a strong sense of momentum for future activities. Several leaders within each group voiced a strong motivation to pursue discussions on urgent strategic orientations.

Qualitative and Quantitative Results

The workshops generated a concrete, comprehensive overview of the perceptions, sources of change, strategic orientations, and actions that subsequently provided the basis for identifying and grouping best practices and facilitating brainstorming sessions. More specifically, the seven strategic orientations became guidelines for the pilot projects chosen by the two regions.

During the Participatory Action Research (PAR) process, stakeholders were able to specifically identify both recent climate impacts and their direct and indirect consequences for various spheres of business. Mobilized stakeholders also identified seven areas for strategic intervention and four regional measures.

What We Know and What We Can Expect

Workshop participants were asked to tell their story and list climate and environmental trends hindering or promoting their business. The Cartesian graph used for this exercise helped stakeholders clarify their own CC perceptions by looking at the probability of occurrences and the magnitude of impacts (positive or negative) on seasonal products in the future (see Bleau et al. 2012; Blangy et al. 2011).

Climate changes can have negative repercussions for sectors offering winter products and positive effects for those operating mainly in warm or summer periods. Despite these findings, there were more negative impacts from CC on winter activities (i.e., climate shifts, rising temperatures, more rainfall, and extreme events), and these outnumbered the positive summer impacts reported by some businesses. Yet, all participants perceived a high probability that identified environmental changes for both seasons will intensify by 2020 (Fig. 2).

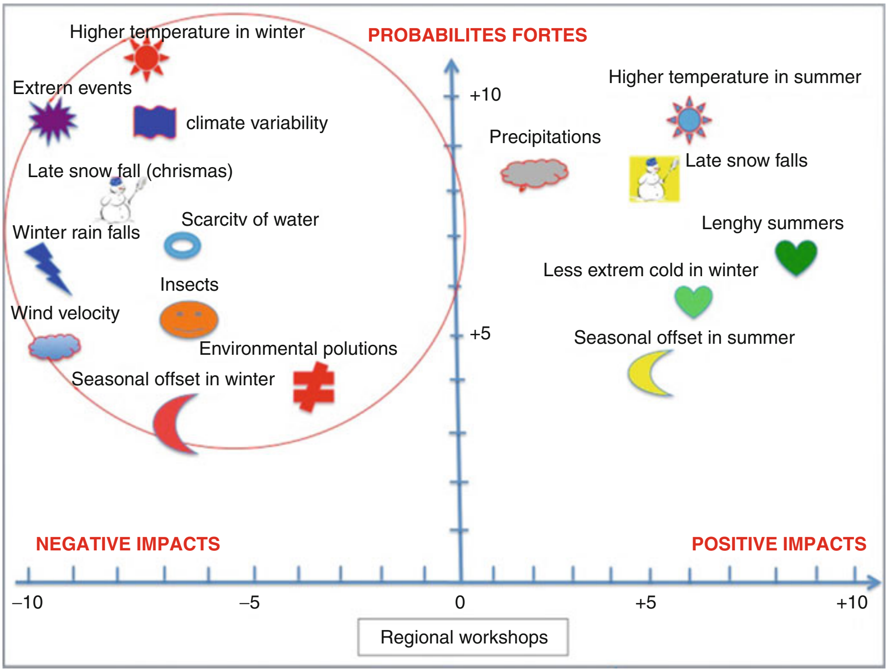

Fig. 2 Perceptions of CC: broad trends, future probabilities, and nature of impacts

Sectoral and regional workshop participants identified repercussions that are already affecting their day-to-day operations. Faced with socioeconomic and environmental challenges at all levels, businesses are adapting reactively to these conditions.

For example, tourism operators must deal with seasonal offset and increased freeze/thaw cycles, increasingly frequent mechanical breakdowns, changing employment conditions, increased snowmaking demand, the changing geography of native species, greater use of natural sites (golf courses and camping grounds), and pressure due to energy and water resource limitations and costs.

Factors Hindering or Promoting the Development of Cross-Country Skiing and Snowmobiling

The force field analysis was performed for the cross-country skiing and snowmobiling sectors (Fig. 3). This tool identified key contributing and mitigating factors (i.e., economic growth and maintained practices). Participants also estimated their degree of control over these factors.

For operators and entrepreneurs, the level of control and flexibility remains highly variable. Results show that real estate development, equipment, and

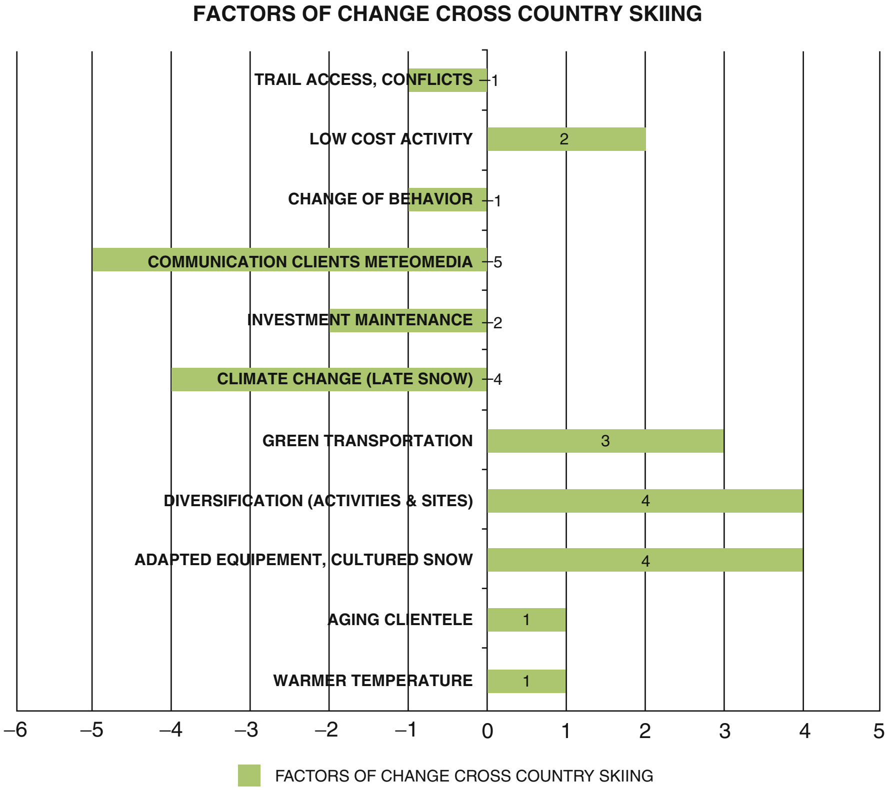

Fig. 3 Force field analysis: factors that hinder and promote the development of cross-country skiing

investment can easily be controlled. Conversely, aspects associated with global temperature (freeze/thaw cycles, rain, and their consequences) appear to be uncontrollable, thus proving that CC is not the main factor generating growth or disrupting operations.

Climate change adds to the range of challenges that tourism sectors are already facing or will be forced to address in order to remain competitive and maintain sustainable growth (Table 3). Operators do not necessarily consider the climate as a strategic risk, even though it affects their businesses at a number of levels they cannot control, such as technical, human, financial, environmental, strategic, image, reputation, and customer levels.

Results from the workshops and questionnaires confirm how each of the four sectors (camping, golf, nature parks, and alpine skiing) rated the challenges. Only alpine skiing mentioned CC as a major concern. Although nature parks indicated severe impacts on cross-country skiing participation in their response to the questionnaire, CC does not appear in their top three concerns. This may be due to a lack of awareness of the subject.

Table 3 Top three challenges faced by operators (questionnaire results)

	Camping	Golf	Nature parks	Alpine skiing
First	Evolving trends and customer habits	Aging population	Labor shortage	**Climate change**
Second	**Climate change**	Competition between destinations or companies	Competition between destinations or companies	Evolving trends and customer habits
Third	Competition between destinations or companies	**Climate change**	Evolving trends and customer habits	Labor shortage

What We Are Already Doing

The perceived and actual changes mentioned in the above exercise encouraged participants to identify strategies already implemented in their businesses and to think of new ones they wished to jointly develop. Six of the strategies listed were selected as being the most relevant, and these were ranked in order of priority, discussed, and illustrated in an action plan (Fig. 4): (1) communication and education; (2) environmental and social responsibility; (3) research, development, innovation, and technology; (4) diversification and maintenance of product quality; (5) planning and infrastructure; and (6) changes to climate policies, practices, and reserve funds.

Small differences were observed between the two regions, based on their different characteristics. Participants from the Northern Laurentian, who are farther and more isolated from the outbound markets (Montreal), insisted on building reserve funds to promote private initiatives. In the Eastern Townships, numerous environmental practices aimed at reducing the ecological footprint have already been implemented and deserve to be highlighted in this study as a source of inspiration for other Quebec regions.

Regarding communication, participants emphasized the need to improve in this respect and provide customers with real-time, accurate information on both regional and daily climate variations.

With regard to environmental responsibility, they agreed on the importance of reducing their ecological footprint and specifically on improving water supply management. On the research/development front, more detailed complementary studies should be conducted, focusing on costs-benefit analyses and snowmaking for cross-country ski centers. Finally, the diversification strategy consisted of designing a four-season concept, developing a multi-activity approach, and combining products in order to compensate for income lost due to changes in seasonal patterns and extreme events.

Although participants had varying needs, this technique was useful to reach common ground in six distinct areas and to think about ways of improving current

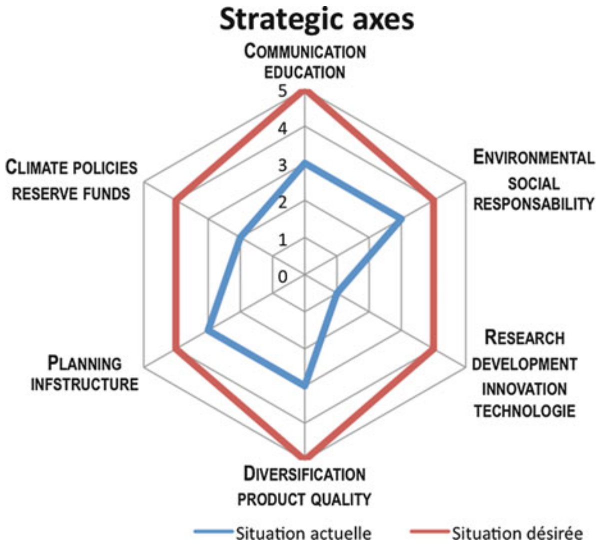

Fig. 4 What we are already doing – existing and possible future adaptation strategies

measures and developing potential adaptation actions to reach the desired scores. Based on the strategic orientations, participants concluded that mitigation actions are far more numerous than adaptation actions, but they recognized that they often confuse the two.

What We Could Do Together

A draft action plan was established based on the radar graph and resulting discussions. This plan included a list of collective activities for improving existing adaptation measures and implementing future ones. Sector-specific adaptation actions were outlined for each of the six strategic orientations. The subsector workshops arrived at this stage more quickly than the regional ones because of their expertise in the area and the fact that they shared common interests.

Brainstorming Sessions: Synthesis of the Five-Step Plan

The final step of this study consisted of regional brainstorming sessions. To obtain the first strategic adaptation framework specific to both the pilot areas, the two groups agreed to select two urgent strategic orientations out of the seven proposed.

Despite the unanimous concern over water scarcity, given the absence of major actors, the Eastern Townships participants agreed to focus on a combined diversification and communication/education (weather extremes) strategy rather than choosing the environmental one. The group concluded that the variations in physical environments, micro-climates, and cross-sector issues prevented them from creating an exhaustive regional view of localized adaptations. Instead, they chose to integrate existing mechanism and policies, in order to accelerate early adaptation to CC at the local level.

As for the Laurentian, that group worked on diversification/maintenance of product quality and research/technology. The need to optimize water supply management to maintain product and service quality was a widespread concern. The alpine skiing, golf, and camping sectors feared that restrictive measures will soon be imposed by local governments. Given the current fact of water variability, a regional cross-sectoral committee was proposed to address this matter.

The brainstorming sessions revealed an individual, territorial approach to adaptation and a need for more concerted action. It also highlighted that weather instability and extremes are major concerns for most nature-based and sports operators because weather forecasts can disrupt people's destination decisions and activity planning and thus affect attendance.

A summary of the discussions yielded two lists of potential adaptation measures for different geographic areas and time frames that were later validated by participants. Initiatives were proposed by public and private stakeholders and actors that could support these actions, some were local (i.e., subregional), while others were regional.

This fifth phase of the five-step plan was followed by ongoing dialogue with regional leaders in order to implement the options that had been prioritized by both regional tourism associations (RTA). Local development bodies emphasized the importance of encouraging tourism entrepreneurs to integrate climate risks in their business plans, in order to prepare for climate/weather uncertainties. The Laurentian RTA has taken a leadership role in educating its outdoor operators on CC impacts and adaptation. Growing awareness and ownership has encouraged local and regional authorities to integrate CC risk management into existing internal policies affecting tourism operations and management. As a result of these outcomes, the tourism in Quebec is now encouraging the research unit to continue the PAR process with other seasonal practices at the national level.

Discussion

This section will focus on the research project structure and management. Discussion will center on how to move from the initial, top-down model to a more flexible and continuous bottom-up approach as a means of addressing adaptation and action implementation in tourism (Fig. 5). Lessons learned throughout the collaborative process and adaptation measures are also featured. Finally, in order to move forward past this initial project, research needs are highlighted by refining tourism and climate scenarios and optimizing knowledge and subsector education in order to promote understanding of regional territorial challenges for adaptation decision making in nature-based and sports tourism.

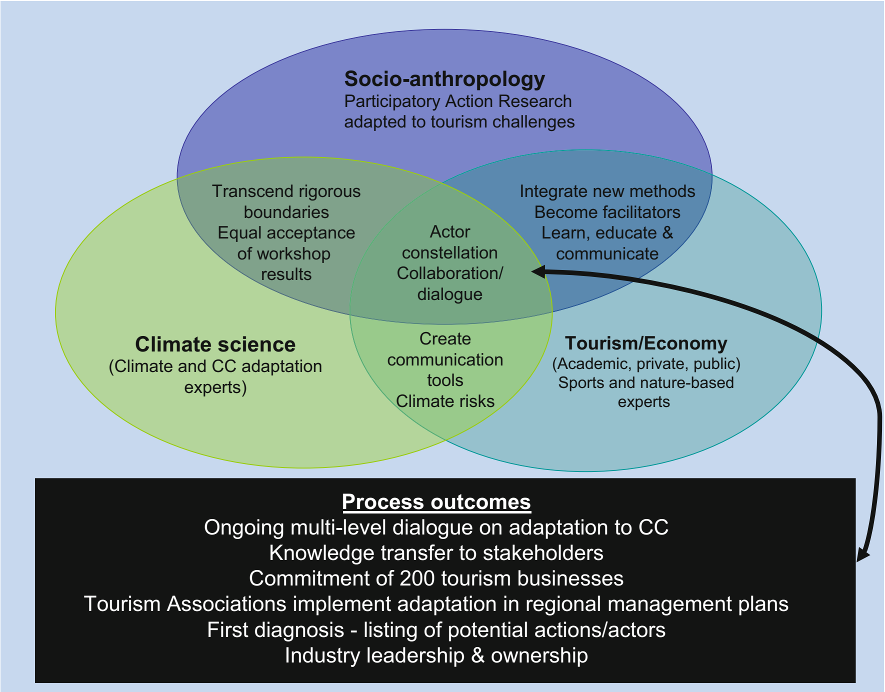

Fig. 5 Transdisciplinary process for progressive learning and management

Project Structure and Management

The use of a traditional structure to manage interconnecting phases and tool production generated many questions with respect to the framework's flexibility, continuity, efficiency, and deadline requirements. This first collaborative experience with private-sector stakeholders has underlined the necessity of involving the industry during initial brainstorming sessions to determine research project objectives and pinpoint adaptation challenges and expectations. This unbiased partnership optimizes trust and the connection between research and practical transformational outcomes. It is argued that this allows the sector to expand knowledge on more critical natural tourism areas, implicate missing subsectors (such as agro-tourism and outfitters), promote greater involvement from nature parks, and include assessment of horizontal issues (i.e., employment, energy supply).

The deliverables for each phase of the research project were planned from the outset. Over the course of the 3-year project, some tasks had to be dropped and others modified because it took more time than anticipated to orchestrate workshops and brainstorming sessions, bring objectives in line with industry expectations, and analyze the vast quantities of data (Table 1 and Figs. 2, 3, and 4). Other tasks were added to address varied levels of awareness and terminology comprehension and the time it was expected users would likely devote to reading complex academic reports.

Communications had to be adjusted to take into account stakeholders' varying skills and awareness levels. Although this step was crucial to a collaborative framework, it was also time-consuming and left less time for data analysis. Coproducing documents means frequently retrieving data and communicating end results to core team leaders who send out the new information. The type of document was therefore called into question and adapted in order to better broadcast and downscale findings to tourism associations, operators, and managers and involve other players.

It is highly suggested by the co-researchers to integrate more flexible media – teaching materials, podcasts, and visual presentations – into the existing scientific reports and technical canvas, as a more malleable data presentation format can well mitigate these inconveniences.

Furthermore, increased trust in the co-researcher unit can facilitate the collection of private primary data, and the more flexible, user-oriented approach will encourage industry leadership and foster ownership of results and tools by improving communication skills and expertise. Also, data retrieval methods that authorities and managers can easily access and understand played a key role in recovering information. In other words, interactive co-construction of synthesis documents from workshops increased accuracy of data retrieval and maintained exchanges between involved parties between interconnecting steps (Figs. 1 and 5).

Subsector and regional experts are best suited to defining the complex business interconnections, needs, and challenges with regard to climate conditions (REDD 2011). It is recommended by Bleau et al. (2012) to set up a permanent CC committee composed of tourism practitioners and researchers (private and public) to elaborate strategic orientations and address significant socioeconomic threats. The ongoing partnerships created through this committee would foster knowledge and information sharing, thereby creating an environment that is conducive to more far-ranging tourism management and policy planning, strategic document formulation, business coaching and education, innovative research, and funding assistance.

Researcher Stance

The project's originality lies in involving a large number of private-sector stakeholders and obtaining their financial support, social engagement, and overall acceptance of adaptation-related PAR techniques. Also, by gathering expertise from a variety of disciplines in order to achieve research objectives, consultants, experts, and researchers had to become more open to flexible structures and visions. Figure 5 illustrates the transdisciplinary overlaps required to connect knowledge systems. The degree of participation, action, and research is often not decided in advance (Hughes 2008). While some tourism experts learn to use new methods and become SAS (Social Analysis Systems) facilitators, climate scientists work on accepting empirical data in the context of social science analysis. Skills are developed in all three disciplines to present climate data in plain language and construct practical tools that are better adapted to the industry.

The collaborative approach linked fundamental questions from the research units to the researcher stance. Researchers and stakeholders were asked to go beyond their familiar scope and boundaries in order to engage knowledge systems and change existing mechanisms (Fig. 5). As stated by Couture et al. (2005), the research documents a process of change and is supported by a constellation of actors who become co-researchers. This innovative approach uses a wide variety of group facilitation techniques combined with fact-based thinking and analytical methods so that the process satisfies the needs and working methods of all stakeholders (Chevalier et al. 2013).

As argued by Daniels and Walkers (2001), an excellent facilitator is key to a successful process. He/she sets the tone for interaction and ensures that the social and physical space is tailored to the participants' needs. Frequent turnover of research personnel hindered not only workshop facilitation but also data analysis and recovery. Expertise in workshop facilitation must be developed as stakeholders wish to continue applying SAS, tools, and techniques.

PAR Process

Customizable SAS techniques were used to design workshops that were adjusted to the multilevel (i.e., global to local) CC context. Indeed, the participants' growing concerns can now be channeled into planning adaptation solutions that are integrated with other contemporary business issues. In other words, adaptation strategies must take other current challenges into account rather than addressing climate change in isolation.

Regional planning should consider all types of enterprises and destinations since CC consequences affect decision making at all levels. Findings show that adaptation strategies are customized in accordance with the pilot areas, the type of recreation and sport businesses located there, and their ability to adapt. Moreover, regions must consider the diversity of products offered in order to assess vulnerability (supply) and make medium- and long-term adaptation decisions (Climalptour 2011). Companies that start by assessing product and service vulnerabilities have a strong focus on risk management and bottom-line protection.

Mobilizing Stakeholders

It comes as no surprise that tourism stakeholders are displaying an increasing interest in current and future CC impacts on seasonal practices, as current information concerning climate change for Quebec's industry is scarce to nonexistent.

Tourism stakeholders recommend pursuing an action-based learning system to guarantee a dynamic, strategic regional plan for the future. The workshops met with widespread satisfaction, providing a forum for equitable and creative discussion of climate issues. It was found that they helped educate stakeholder networks by connecting knowledge from different disciplines. Moreover, informed leaders play a key role in disseminating this integrated CC and adaptation information to their colleagues. On the contrary, Muro and Jeffrey (2006) criticized the difficulty of observing actual learning outcomes of participatory processes.

The process proved difficult at times, in part because various stakeholders had different understandings of the problem, agendas, and priorities. Initially stated by O'Brien (2009), research results also show that values and interests play an important yet seldom-discussed role in climate change responses and influence the adaptation strategies that are prioritized by different groups.

Strategies and Measures

Even if operators do not consider CC to be a strategic risk, it nevertheless affects their businesses on a number of uncontrollable levels. Their response to the lack of current information about weather and climate variations therefore consists of flexible packages, investment in technologies, partnerships, and product diversification. While there is nothing inherently wrong with these strategies, as the first step, the tourism industry needs to focus on improving adaptation capacity and its ability to assess vulnerabilities in areas of great natural and economic value.

Entrepreneurs in pilot regions generated solid information that led to seven strategic development interventions and a list of potential adaptation measures containing 30 new initiatives. The dynamic nature of these outcomes means they can serve as a starting point for a second collaborative research project. Regional tourism associations (RTA) have taken the lead by implementing adaptation in existing practices and mechanisms such as management plans (Fig. 5).

Current local reactive and voluntary adaptation actions can be found in the final report (Bleau et al. 2012). In practice, there were more mitigation than adaptation measures. This can be largely attributed to the fact that first provincial framework on CC overlooked the adaptation aspect of business planning.

While inspired by international initiatives, the business sector found them difficult to transpose into their own socioeconomic context, because of the Quebec-specific nature of national/regional/local structures, geography, and cross-sector issues. Given the current lack of government incentives, their main concern remains funding sources for future sustainable projects.

Research Needed to Integrate Adaptation

Future uncertainty makes planning a difficult task for small and medium-sized businesses and regions. Based on the results of the PAR process, six elements were identified as essential to provide future support to policy and managerial decision making at all levels: (1) ground proofing (comparing case studies);

(2) quantified information from cost/benefit studies; (3) connections between local businesses/destinations and regions; (4) transformational change in existing mechanisms and business models; (5) applied tools for users; and (6) government bodies, associations, and business coaching.

Conclusion

A collaborative research model developed specifically to better understand the impacts of CC on Quebec's nature-based and sports tourism has highlighted fruitful elements for further exploration. The transdisciplinary approach resulted in a learning process that led to team building and an exchange of methods and techniques. Overlaps between disciplines are key focuses to the progressive adaptation of the tourism sector (Fig. 5). The project's first diagnosis has clarified the benefits of adopting a more flexible framework, developing continuous partnerships, and co-constructing interactive documents for regional and local adaptation responses.

Throughout this project and hereafter, a sustained effort to democratize climate science knowledge for multilevel tourism stakeholders has improved their understanding of adaptation and risk management. Indeed, CC has become a motive for combined efforts to rethink core aspects of the tourism industry as a whole in light of recent extreme events and future uncertainties. The outcome of this research project calls into questioning the old economic development model and puts forward a new model that repositions the industry with a focus on combined economic growth and sustainability.

Committed participants now focus on evaluating both individual and regional assets to improve and personalize territorial decision making. Also, prudent risk management suggests companies should recognize outcomes and consider ways to anticipate the effect of long-term climate trends. Furthermore, researchers must take a nuanced approach when interpreting climate and tourism scenarios, as both their results and scientific forecast tools are often called into question. In fact, financial institutions are increasingly taking CC into account when granting and guaranteeing loans. Already considered at risk by these institutions, the tourism sector is sensitive to climate conditions. It is therefore in the interest of these companies to put forward innovative CC adaptation strategies to minimize the associated risks and take advantage of potential economic opportunities.

More than 200 businesses and 300 participants from different tourism subsectors took part in this collaborative process to raise awareness and mobilize the industry. The tourism sector expects guidance in the adaptation process. Pilot regions and subsector leaders have become knowledge ambassadors and wish to use existing synergies and identified potential adaptation responses to make further progress. While Quebec's tourism sector is inherently dynamic and flexible, it also foresees the need to draw in other regions and get the provincial government involved.

The role of the Transat Chair in Tourism is to develop research expertise to ensure knowledge advancement and support seasonal activities in the adaptation process in order to ensure collaboration and education. As a leading partner, the Chair hopes to build partnerships with other tourism regions (both here and abroad) to develop efficient coping strategies and pursue dialogue on sustainable development and tourism in the context of CC.

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An Analytical Framework for Investigating Complex Institutions in Climate Change Adaptation: The Institutional Environment Matrix

Sining C. Cuevas, Ann Peterson, and Tiffany Morrison

Contents

Abstract

This chapter introduces the institutional environment matrix (IEM), a diagnostic and planning framework designed to analyze complex institutional environments and determine the institutional fit of climate change adaptation responses. The framework argues that the institutional environment is comprised of rules, social structures, and organizations. It establishes the vital role of institutional arrangements in characterizing the functions and functional interdependencies of institutions. The IEM framework has a dual layer design that allows complex

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institutional relationships to be examined across scales. The institutional environment layer is a comprehensive inventory of institutions that outlines institutional complexities. The institutional matrix layer is the system of institutional arrangements that determines the functional interdependencies of institutions. The matrix explores institutional interplay in relation to several general institutional functions: reducing uncertainty, connecting individuals to society, fostering adaptive capacity, and mobilizing resource utilization. By providing a structure to examine complex institutional relationships, the IEM is a significant innovation for assessing the institutional fit of and interplay between existing and planned climate change adaptation responses. This framework may also be used as an analytical tool in adaptation planning and evaluation.

Keywords
Institutions • Institutional environment • Climate change adaptation • Analytical framework

Introduction

Urban and rural systems are increasingly subject to complex and uncertain problems such as climate change, biodiversity loss, land-use conflict, pandemic disease, and rapid market fluctuations. These problems challenge the abilities of societies to manage change in traditional ways. Subjective perceptions, cross-sectoral misunderstandings, and technological contingencies only increase this challenge (Gunderson and Holling 2002; Crowder et al. 2006). Institutions play a critical role in ensuring successful adaptation to rapid and unpredictable change yet are one of the least examined and ambiguous aspects of climate change adaptation (O'Riordan and Jordan 1999; Adger 2000; Adger et al. 2005a, b).

Following the works of North (1990) and Ostrom (1990), several facets of institutions have been examined in the literature (Young 2002; Sabatier 2007; Oberthür and Stokke 2011). Recently, of particular interest to scholars are the linkages between institutions, climate change, and adaptation with studies addressing the effects of institutional barriers and constraints on adaptation (Inderberg and Eikeland 2009), the fundamental functions of institutions in facilitating climate change adaptation (Rodima-Taylor 2012), and the institutional requirements for adaptation (Adger et al. 2005a). Yet, despite these works, the research area is still in its infancy, as evidenced by a number of competing frameworks.

To analyze these institutional concerns more effectively, scholars have developed a variety of frameworks to examine the role of institutions in the context of climate change adaptation. These analytical frameworks are differentiated by how they define institutions – in essence, whether they consider institutions as rules, social patterns of behaviors, or organizations. In other words, the types of analysis that can be performed using these frameworks are bound by the frameworks' institutional perceptions.

For example, one framework that focuses on organizational institutions examines the institutional linkages between and among public, private, and civil society institutions and the significance of institutional partnerships in enabling adaptation. It provides a tool to analyze organizational partnerships and the impacts of these associations on the access of vulnerable social groups to resources (Agrawal 2008). Another framework that defines institutions in terms of rules, customs, and norms concentrates on the intrinsic characteristics of institutions in influencing the behaviors of individuals and in fostering collective action. Essentially, this framework deals with understanding and assessing the ability of institutions to raise the adaptive capacity of society (Gupta et al. 2010).

This raises two significant issues. First is the disharmony in defining institutions in the context of climate change. Research has focused on institutions as rules and social structures (O'Riordan and Jordan 1999; Eriksen and Selboe 2012) and also as organizations (Agrawal et al. 2008; Vallejo 2011). Therefore, as climate change research advances, there is a discrepancy on how the concept of institutions is founded. Second is the inability of the frameworks to simultaneously analyze the various facets of institutions. If these gaps are not addressed, it can lead to a divergence in institutional concepts and the direction of research.

To address the first concern, a conceptual framework was developed that defines institutions as a triad of rules, social structures, and organizations in the context of climate change adaptation. Thus, institutions are the commonly known and acknowledged rules, social structures, and organizations founded on common belief systems that transform individual acts and expectations into collective actions; convert personal values into social norms and shared beliefs; and define the formal and informal behavioral systems of human existence. As an extension of this endeavor, this chapter develops an analytical framework that helps to examine the complexity of the triad institutions in climate change adaptation responses.

Institutional interventions formulated and implemented to adapt to climate change bring either conflict or harmony into existing institutions and arrangements (Young 2002; Nilsson et al. 2012). A framework that can be utilized to examine the relationships between and among rule-based, social structure-based, and organizational institutions is useful in planning for and evaluating the effects of these institutional changes. Moreover, the efficiency and success of adaptation responses rest on how they fit in the institutional environment and institutional arrangements that are in place (Theesfeld et al. 2010). Every case has a unique institutional environment or *array of institutions that influence and affect climate change adaptation behaviors and decisions*. Therefore, the institutional fit of the adaptation measures, i.e., *whether adaptive institutional interventions are synchronized or in harmony with the existing institutions*, is vital to effectively implement an adaptation response. The more fitting the adaptive institutions are with the other institutions in the system, the better each institution performs and, thus, the more relevant each one becomes.

This chapter is divided into two major parts. The first establishes the theoretical foundations of the framework by presenting the concept of institutions as rules, social structures, and organizations in the context of climate change adaptation (Institutions in Climate Change Adaptation Planning); examining the concepts of institutional

Table 1 Definition of key terms

Term	Definition
Rule-based institutions	Constraints that structure political, economic, and social interactions and determine decisions, actions, information, payoffs, and actors in various conditions and situations (North 1990; Ostrom 1990)
Social structure-based institutions	Self-sustaining, salient patterns of social interactions (Aoki 2007) that form individual and social expectations, relations, conduct, interactions, and behavior (Agrawal 2008)
Organizational institutions	Structures of power that form the social, economic, legal, and political organizations of a society (O'Riordan and Jordan 1999; Acemoglu and Johnson 2005)
Institutional arrangements	Structures of the rules that govern human decisions (Tang 1991) or the specific guidelines designed to facilitate social interactions (Klein 2000)
Institutional fit	State where the adaptive institutional interventions are synchronized or in harmony with the existing triad of institutions – rules, social structures, and organizations
Institutional interplay	Interactions and reactions between and among institutions that build institutional linkages, relationships, and interdependencies
Functional interdependencies	Relationships built resulting from the interactions among the arrangements that allow institutions to perform their functions
Institutional environment (IE)	Comprehensive inventory of the differing institutions – rules, social structures, and organizations – that may influence adaptation responses
Institutional matrix (IM)	System of institutional arrangements that determines the functional interdependencies of institutions
Institutional environment matrix (IEM) framework	A planning and diagnostic framework designed to analyze institutional environments and determine the institutional fit of climate change adaptation responses

Sources: North (1990), Ostrom (1990), Tang (1991), O'Riordan and Jordan (1999), Klein (2000), Acemoglu and Johnson (2005), Aoki (2007), and Agrawal (2008)

arrangements (Institutional Analysis and Institutional Arrangements); and classifying institutional functions (Institutional Functions). The second part synthesizes these concepts (Institutional Environment Matrix Framework) to form a framework termed as the institutional environment matrix (IEM). In developing the IEM, this paper adopts the definitions established by other authors and develops some new definitions befitting the context in which they are used (Table 1).

Institutions in Climate Change Adaptation Planning

There are varying notions of what constitutes an institution. Institutions are rules, procedures, conventions, and protocols in rational choice, economics, and game theory; moral templates, cognitive scripts, and frames of meaning in sociology and

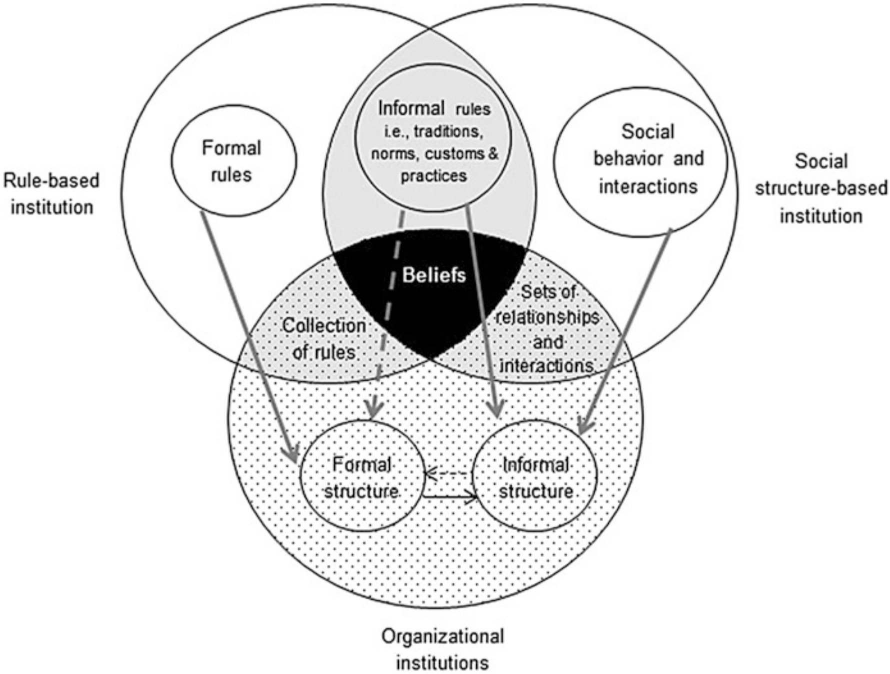

Fig. 1 A conceptual framework for institutions in the context of climate change adaptation (Source: Authors)

anthropology; and organizations in comparative politics and state theory (North 1990; Jordan and O'Riordan 1997; O'Riordan and Jordan 1999; Markvart 2009).

In climate change adaptation, institutions should have a synthesis of definition that has cross-disciplinary relevance. Therefore, institutions are the commonly known and acknowledged rules, social structures, and organizations founded on common belief systems that transform individual acts and expectations into collective actions; convert personal values into social norms and shared beliefs; and define the formal and informal behavioral systems of human existence. Hence, rules, social structures, and organizations are all institutions.

The core relationships among the three forms of institutions are illustrated in the Venn diagram (Fig. 1). Rules, social structures, and organizations are linked through a system of beliefs that allow them to exist and continue to persist as institutions. The beliefs associated with rules and organizations are significant components shaping the self-enforcing expectations, which consequently affect behavior and motivate individual actions (Greif and Kingston 2011). The belief system itself is a part of what constitutes social structure-based institutions (Nelson and Sampat 2001; Nelson and Nelson 2002).

Rule-based and social structure-based institutions are further linked through informal rules. This linkage is shown in the overlap between the spheres representing rule-based and social structure-based institutions (Fig. 1). Together with formal rules, informal rules such as practices, norms, and traditions comprise part of the rule-based institutions.

Formal rules define the hierarchical structure, decision-making powers, contracts, and property rights allocation in the political and economic systems (Pejovich 1995). Meanwhile, informal rules determine individual interactions and are engraved in society's culture and heritage (North 1990; Hasan 2000; Hodgson 2006). These same social patterns of behaviors are the elements that form social structure-based institutions (Nelson and Sampat 2001; Aoki 2007).

The conceptual framework considers organizations as an assembly of rules and contracts that operate through some type of relationship among individuals. This perception interlaces organizations – perceived as a "collection of rules" (March et al. 2011, p. 239) – with the rule-based institutions. Organizations rely on the norms and patterns of behaviors to be implemented (Hodgson 2006), which tie organizations to the social structure-based institutions.

The formal and informal structures of organizational institutions are rationalized by the formal rules and social customs, values, and beliefs, respectively (Meyer and Rowan 1977; Shafritz et al. 2005). Formal rules are the written and legally sanctioned rules, whereas informal rules are represented by the unwritten social patterns of interactions and behaviors (Nabli and Nugent 1989). Formal rules are usually applied, managed, observed, and monitored by formal political, legal, and government institutions. Conversely, informal institutions fall under the private realm (Williamson 2009).

Formal structures have a special relationship with informal rules (illustrated by the broken arrow linking the two factors) (Fig. 1). Formal organizations are created and legitimized by formal rules, whereas the relationships among the members of formal organizations are typically governed by informal rules. Hence, "in every formal organization, there arise informal organizations" (Shafritz et al. 2005, p. 205), thereby forming an additional linkage between formal and informal organizations (indicated by the broken arrow between the two entities). This relationship denotes that informal organizations do not directly affect the structure, composition, or creation of formal organizations. However, informal organizations are defined as collective behaviors (in the form of organized groups of people) that influence the choices and decisions of the formal organizations' members. Meanwhile, formal organizations directly affect informal organizations through the formal rules they implement or the actions they perform (solid arrow in Fig. 1). In essence, "the root of informal systems are imbedded in the formal organization itself and nurtured by the very formality of its arrangements" (Shafritz et al. 2005, p. 205). For example, a formal organization that funds the activities of an informal organization may influence the latter to become formal itself, especially if formality is a requirement to gain further financial assistance. Alternatively, the funds provided may have allowed the informal organization to expand its operations, with the transition to a formal structure being essential to continue these new activities.

This unified definition of institutions is vital in analyzing linkages among climate-adaptive institutions. Climate change impacts include extensive aspects of human existence (i.e., social, economic, political, ecological, and environmental).

Hence an amalgam of ideas from various disciplines befits the concept of institution in the climate change adaptation context. This synthesized definition should be further investigated, particularly in relation to how rules, social structures, and organizational institutions function together in systems where adaptation responses are applied.

Institutional Analysis and Institutional Arrangements

Institutional arrangements are critical to address the climate change challenge as adaptation "never occurs in an institutional vacuum" (Agrawal et al. 2008, p. 2). The success of adaptation practices rests on specific institutional arrangements, such as well-defined property rights that address resource access and risk exposure (Agrawal 2008). For example, building a seawall would not depend only on the physical construction of the structure itself, the costs associated with it, or the science that projects the rate of sea level rise. It also would be affected by the rules governing property (Caldwell and Segall 2007), including the agreements on the allowable height, thickness, and length of the structure; the social norms of the communities affected by the predicted sea level rise and storm surge; and the rights of private property owners. Therefore, developing suitable adaptation responses entails institutional arrangements that enable these measures to be implemented (Rodima-Taylor 2012, p. 12).

Arrangements in Rule-Based and Social Structure-Based Institutions

Institutional analysis assumes that institutional change will affect some areas of reality that already are exposed to existing institutions. Therefore, the environment where the institutional changes (e.g., the creation of new policies or amendments in prevailing regulations) are to be implemented must be understood first before the possible consequences of such changes can be determined (Theesfeld et al. 2010). More importantly, intensive institutional analysis involves understanding the detailed working rules and norms that influence people's decisions (Ostrom 2011).

In **rule-based** and **social structure-based** institutions, these rules exist at three levels, namely, operational rules, collective-choice rules, and constitutional-choice rules (Ostrom 1990). Among the three, constitutional-choice rules are the most extensive. They are the basis of all rules – the set which determines who and what (specific rules) are authorized to create the other levels of rules. Next in the hierarchy are the collective-choice rules – the rules created to resolve conflicts, impose decisions, and formulate or transform operational rules (Ostrom 1990). Essentially, they are the rules which underpin operational rules (Tang 1991). Lastly, operational rules are those that directly influence the daily decisions about who oversees the actions of others and how or who takes part in which situation, what information must be given, what are the participants allowed to do, and what rewards or penalties will be designated to various sets of acts and consequences. Operational rules are typically known as policies (Ostrom 1990).

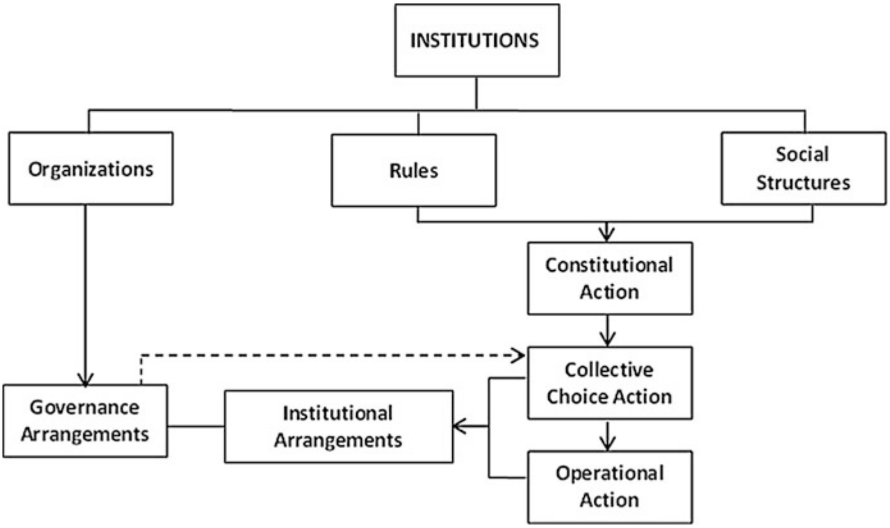

Fig. 2 Institutions and institutional arrangements (Source: Authors)

Ostrom's (1990) classic text, "Governing the Commons," identified specific processes at each level of rules. Operational rules cover appropriation, provision, monitoring, and enforcement; the collective-choice level encompasses policy-making, management, and mediation of policy decisions; and the constitutional level includes formulation, governance, adjudication, and modification of constitutional decisions. Through these rules, institutions are able to affect and influence individual and collective actions. For instance, operational rules, such as those that specify fishing technologies permitted at a particular fishing ground, constrain and predict operational actions. Similarly, collective-choice rules are translated into collective-choice actions and constitutional rules into constitutional-choice actions (Schlager and Ostrom 1992). These levels of rules form the categories of institutions (Feder and Feeny 1991). The constitutional-choice rules comprise the constitutional order, whereas the *collective-choice rules and operational rules constitute institutional arrangements* (Fig. 2) (Feder and Feeny 1991; Tang 1991).

Institutional arrangements are the structure of rules governing human decisions (Tang 1991) or the specific guidelines which facilitate social interactions (Klein 2000). Institutional arrangements are also sets of rules or agreements with a common objective (e.g., contract) that preside over the activities of people. For instance, a group of farmers may enter into an agreement to jointly purchase agricultural inputs or supply products to buyers, thus forming a producer's organization (Eaton et al. 2008). Institutional arrangements likewise identify an individual in relation to others within the group that she/he belongs to, as well as with those outside the group. For example, in property regimes, the property relation between individuals is defined by the interest of one that is protected by virtue of the right and the duty of others to follow the arrangement (Bromley and Cernea 1989). Institutional arrangements, therefore, guide individual behaviors toward collective actions.

Arrangements in Organizational Institutions

In terms of **institutional organizations**, institutional arrangements involve the system of (organizational) units that plan, support, and/or implement programs, practices, and actions. These arrangements include the linkages between and among organizations at different administrative scales (national, regional, state, provincial, and local) or sectors (economic, political, legal, social). They also represent relationships between government and nongovernment units such as households, communities, and civic organizations (Mattingly 2002). As institutions, organizations are governing structures that motivate collective behaviors and actions (Nelson and Sampat 2001; Williamson 2009), while institutional arrangements are the **governance arrangements** (Klein 2000; Kooiman 2008). Institutional arrangements oversee the relationships and interactions between, among, and within groups of individuals and, thus, influence the variability of commitments of institutions to governance (Klein 2000; Andersson and Ostrom 2008). These ideas are significant because they link organizational arrangements to the rule-based and social structure-based arrangements (Fig. 2). To illustrate, policy goals depend on the set of dominant actors and ideas in the area and when these policy debates and decision-making occur. Governance arrangements then determine the aims and the general implementation preferences of policies, regulations, and state-society interactions (Howlett 2009).

Institutional arrangements allow multiple types of linkages between and among institutions (Heikkila et al. 2011). As guidelines, they are the means by which institutional interplay (i.e., in the form of functional interdependencies or consequences of institutional design and management) is implemented (Young 2002). Accordingly, institutional interplay refers to the interactions among institutions that build institutional relationships (Young 2002). Institutional interaction is determined by the impact of one institution on another, thereby exhibiting causation (Gehring and Oberthur 2009; Oberthür and Stokke 2011). Thus, the effect or interaction will not be observed without a stimulus and a receiver. The stimulus is the source institution (independent variable), and the receiver is the target institution or system (dependent variable) (Gehring and Oberthur 2009). For example, an introduced institutional adaptive measure (the independent variable) will interact with the existing institutions in the system (the dependent variable). Institutional interplay, however, is not one directional. Interplay involves functional interdependencies (Young 2002; Linnér 2006) and thus includes mutual influences or effects. Although the interaction may be triggered by a stimulus, the outcomes or institutional linkages are the result of the institutional integration. Therefore, the interplay exists in the . institutional environment comprised of the adaptive institution and the other existing institutions.

Institutional interactions may be complementary, neutral or coexisting, counterproductive, conflicting, or overlapping (Gunningham and Grabosky 1998; Young 2002; Nilsson et al. 2012). In relation to the triad institutional concept introduced in this chapter, institutional linkages encompass relationships within, between, and among laws, policies, regulations, traditions, norms, practices, government units, civic organizations, and community groups, among others. Institutional linkages must be understood to determine how institutions influence adaptation practices and responses (Agrawal 2008). Consequently, institutional functions in the context of this institutional definition should be determined to understand the institutional fit of adaptation responses.

Institutional Functions

Institutions are crucial in promoting successful adaptation to climate change. They influence key decisions in the system, shape the direction of adaptation efforts, frame the adaptive capacities of systems, and enable collective action toward attaining the adaptation goals (Næss et al. 2005; Agrawal et al. 2008; Eriksen and Selboe 2012). Institutions accomplish these tasks through their innate characteristics and the functions they perform.

Institutions, as rules, social structures, and organizations serve the same functions, thus they are interdependent. These institutional functions can be classified into four main types, namely, reducing uncertainty (by forming individual and social expectations), connecting individuals to society, fostering adaptive capacity, and mobilizing resource utilization. These functions are performed by all institutional types, thereby, strengthening the interconnections among these institutions (Fig. 3).

The different characteristics of rules, social structures, and organizations limit their respective capabilities to perform some of these functions. For example, organizations (as a collection of rules and bundles of relationships and interactions) can establish systems of power and authority and identify the people included and excluded from the organization. However, the entirety of organizations, including their characteristic as "actors" (Gupta et al. 2010), constrains the organizations' ability to create rights and entitlements but promotes their capacity to deliver external resources into the system (Table 2).

Reduces Uncertainty

Institutions **reduce uncertainty** by forming individual and collective expectations and by developing a constant structure of social interactions (North 1990; Ostrom 1990; Kirsten et al. 2009; Brousseau et al. 2011). They also provide stability and predictability by *establishing the power and authority systems* (O'Riordan and Jordan 1999; Acemoglu and Johnson 2005; Berman et al. 2012) and *creating rights and entitlements* (Ostrom 1990). Institutions also *identify inclusions and exclusions* by determining which actions are permissible and the conditions by which to undertake certain activities (North 1990; Ostrom 1990; Klein 2000). By outlining constraints, institutions set up the boundaries for each individual and society as a whole (Ostrom 1990). For example, as an institution, property rights form expectations that the claims to the property would be respected and be abided by all, thereby reducing the uncertainty associated to these claims (Bromley and Cernea 1989).

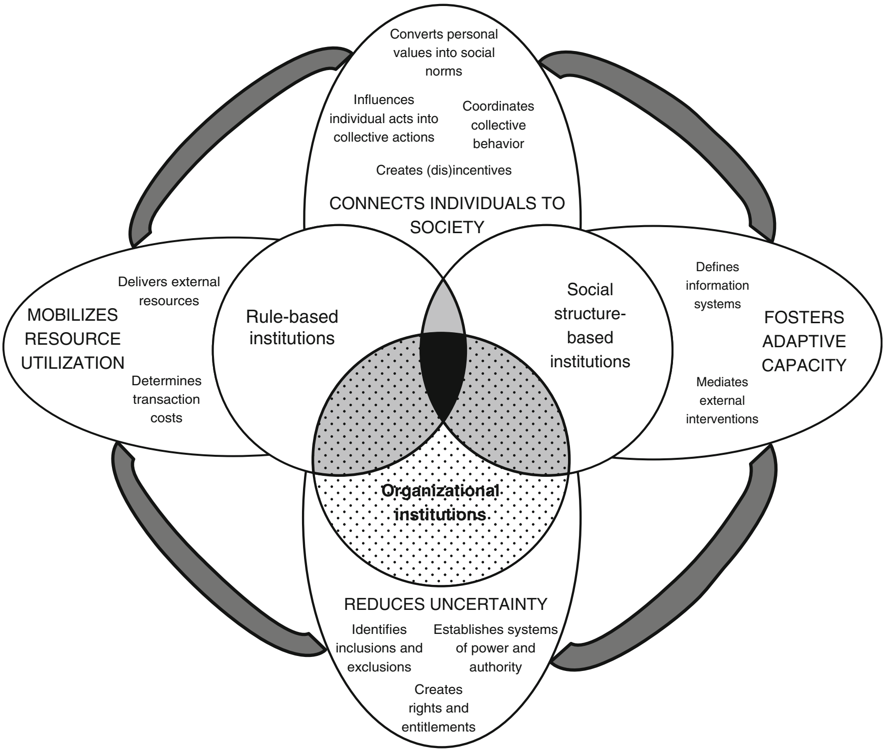

Fig. 3 Functions of institutions (Source: Authors)

Connects Individuals to Society

Institutions **connect individuals to society** by giving everyone a shared identity (Jentoft 2004). They *convert personal values into social norms and shared beliefs* as individuals get emotionally attached and identify with the institutions. This function is specifically attributed to social structures, informal rules, and informal organizations. Thus, institutions become the social standard for understanding and reacting to circumstances, which accordingly become the source of people's compliance and submission to institutions. As such, institutions *influence and transform individual acts and expectations into collective action*s (Kirsten et al. 2009).

Institutions also *create the incentive structure* that determines the actions of people as individuals and as a society (Agrawal 2008). Incentive structures incorporate behavioral patterns that encourage actors to change norms and practices, implement the changes, uphold the changes, and stand by the decisions to change (Biermann 2007; Gupta et al. 2010). Thus, incentive mechanisms enable individuals to choose how to respond efficiently to goals and objectives such as those of climate change adaptation (Young 2002). Conversely, institutions also influence

Table 2 Institutional functions by type of institution

Functions of an institution	Types of institutions					Features/ descriptions
	Rules		Social structures	Organizations		
	Formal	Informal		Formal	Informal	
Reduces uncertainty						
Establishes systems of power and authority	✓	✓	✓	✓	✓	Actors and actions involved in decision-making; who has the authority and what kind of authority
Identifies inclusions and exclusions	✓	✓	✓	✓	✓	Scope and jurisdiction of actors (who) and actions (what) allowed and constrained
Creates rights and entitlements	✓	✓	✓	×	×	Claims, privileges, etc. to resources, i. e., access rights, management rights
Connects individuals to society						
Converts personal values into social norms and shared beliefs	✓	✓	✓	✓	✓	Social principles, beliefs, and philosophies
Influences and transforms individual acts and expectations into collective actions	✓	✓	✓	✓	✓	Plans and programs for collective efforts and actions
Creates (dis) incentives for individual and collective actions	✓	✓	✓	✓	✓	Rewards and penalties; payoffs on actions
Coordinates individual or collective behaviors	✓	✓	✓	✓	✓	Management of multiple efforts

(*continued*)

Table 2 (continued)

Functions of an institution	Types of institutions: Rules – Formal	Rules – Informal	Social structures	Organizations – Formal	Organizations – Informal	Features/ descriptions
Fosters adaptive capacity						
Defines information systems	✓	✓	✓	✓	✓	Provision of information (who, what, when, where, and for whom)
Mediates external interventions	✓	✓	✓	✓	✓	Access to and management of outside resources (how, what, when, where)
Mobilizes resource utilization						
Means of delivery of external resources	×	×	×	✓	✓	Actors facilitating access to outside resources (who and for whom)
Determines transaction costs of activities and decisions	✓	✓	✓	✓	✓	Integration of multiple efforts; internal costs (financial or otherwise)

Sources: North (1990, 1994), Ostrom (1990), O'Riordan and Jordan (1999), Jentoft (2004), Acemoglu and Johnson (2005), Pfahl (2005), Agrawal (2008), Adkisson (2009), Dorward and Omamo (2009), Kirsten et al. (2009), Gupta et al. (2010), Greif and Kingston (2011), and Berman et al. (2012)

behaviors by providing disincentives or penalties to various actions and consequences (Ostrom 1990). Thus, choosing to conform to institutional arrangements becomes attractive.

Institutions are also the *means by which people coordinate their beliefs*, *interactions*, *and activities*, thereby affecting how individuals and society make decisions (Pfahl 2005; Adkisson 2009; Greif and Kingston 2011). For instance, the local governing body in the Carteret Island in Papua New Guinea (i.e., the Council of Elders) organized the voluntary relocation of community households to the main island of Bougainville (Rakova 2009). Labeled as one of the first climate change refugees, the Carteret people were forced to leave their homes due to the accelerated sea level rise and the worsening extreme coastal events in the area (Boano et al. 2008). The Council formed a nongovernment organization, named Tulele Peisa, which designed and administered the Carterets Integrated Relocation Programme (CIRP) (Rakova 2009; Boege 2011). In this case, the organizational institutions such as the Council of Elders and the Tulele Peisa were vital in planning and mobilizing the relocation efforts. The community's norms and traditions authorized the organizations (specifically the Council of Elders) to make decisions for the whole community. Meanwhile, the CIRP guided the people on how to follow through with the community resettlement. Thus, the social and cultural norms, organizations, and formal policies all affect how an individual, a household, and/or a community responds to climatic and other stressors (Young 2002).

Fosters Adaptive Capacity

Institutions are critical in **building the adaptive capacities of systems** (Berman et al. 2012; Pradhan et al. 2012). They *affect information systems* (Dorward and Omamo 2009) and strengthen the ability of vulnerable communities to prepare for the impacts of climate change. They influence the flow of information, the types of studies undertaken, and the interpretations made from the research results (March and Olsen 1996). Moreover, they influence the kind of information to be disseminated (Ostrom 1990) and how this knowledge is disseminated (Agrawal 2008).

Institutions are *mediators of external interventions* that affect how individuals, communities, and social groups utilize assets and resources (Agrawal 2008). Institutions provide leadership, facilitate negotiations, and create networks with other institutions such that external interventions can be systematically filtered, effectively absorbed, accepted, or refused (Agrawal 2008; Rodima-Taylor 2012). For example, a culture of solid community ties suggests an accommodating attitude for external interventions promoting community-based management; but the reverse can be expected if individualism is the norm.

Mobilizes Resource Utilization

In mediating external interventions, organizational institutions are the *means by which the external resources that facilitate adaptation are delivered*, and they accordingly administer access to such resources. These resources may be information, technical inputs, and/or financial support. Institutions "mediate the extent to which climate change affects communities" (Pradhan et al. 2012, p. 9); therefore, they are crucial to the successful implementation of externally facilitated adaptation strategies (Agrawal 2008).

Institutions matter because they *determine the cost of transacting* activities (North 1994) and are comprised of "transaction-cost–reducing arrangements" (Kirsten et al. 2009, p. 43). Transaction costs pertain to the costs incurred from the activities that lessen the risk of transaction failure such as planning, negotiating, creating, monitoring, and enforcement of an agreement. These also include the costs of maladaptation, bargaining, and other operations related to governance and securing the commitment of actors to the contracts (Kirsten et al. 2009). Institutions will fail to reduce transaction costs if the institutional context where the transactions take place is in disarray (Theesfeld et al. 2010).

Similarly, a weak institutional environment, specifically in terms of legal frameworks, makes it difficult to enforce contracts and agreements that exchange goods and services and to coordinate activities (Eaton et al. 2008). The norms and practices existing in the system also affect the cost of transactions. For example, if bribery is the custom, then people may bribe corrupt law enforcers to accomplish their goals. Costs would include resources (e.g., money, time, and people) in bribing transactions plus the regular expenses incurred in undertaking such tasks. If the rule of law is upheld, then bribing will be useless and the associated costs will not exist. Likewise, if cheating is the norm, then there will be additional costs to prevent other parties from cheating. The effectiveness and efficiency of actions and activities depend on the institutional environment and arrangements in place.

Interdependencies and linkages among institutions occur through these functions. These associations are the product of the interactions between and among institutional arrangements (Young 2002). In this sense, functional interdependencies can be defined *as the relationships between institutions resulting from the interactions among arrangements that allow institutions to perform their functions*. These linkages are explored in the IEM framework that analyzes the institutional environment in adaptation responses.

Institutional Environment Matrix Framework

The proposed framework incorporates two layers, the **institutional environment** (**IE**) **and institutional matrix** (**IM**) (Fig. 4). The institutional environment focuses on a specific type of system, a particular adaptation goal, or a type of adaptation strategy. It is a *comprehensive inventory of the differing institutions – rules*, *social structures*, *and organizations – that may influence adaptation responses*. This layer assumes that examining the institutional environment in assessing and planning for climate change adaptation responses is a significant feat. For instance, the coastal management and governance arrangements in the East of England showed that there exist:

> three central government departments, four regional bodies, five statutory agencies, four ad-hoc groupings, seventeen local authorities, and four forums with an interest in coastal planning, but not necessarily working together. . .. five sets of overlapping plans, fourteen designations of coastal sites and landscapes, a mix of management bodies, many organizational cultures, un-coordinated organizational activity at different scales, and overlapping jurisdictions, responsibilities and functions. (Nicholson-Cole and O'Riordan 2009, p. 373)

Analyzing or planning for adaptation responses incorporates an exhaustive assessment of the institutional environment in which these responses have been or will be applied. This is important in institutional analysis because the number of institutions in a given system is directly related to the rate and complexity of the institutional linkages (Young 2002).

The institutional matrix (IM) can analyze the interactions among the arrangements. It is defined as the *system of institutional arrangements – including operational and collective-choice rules and governance arrangements – that determines the functional interdependencies of institutions*. This layer examines the various

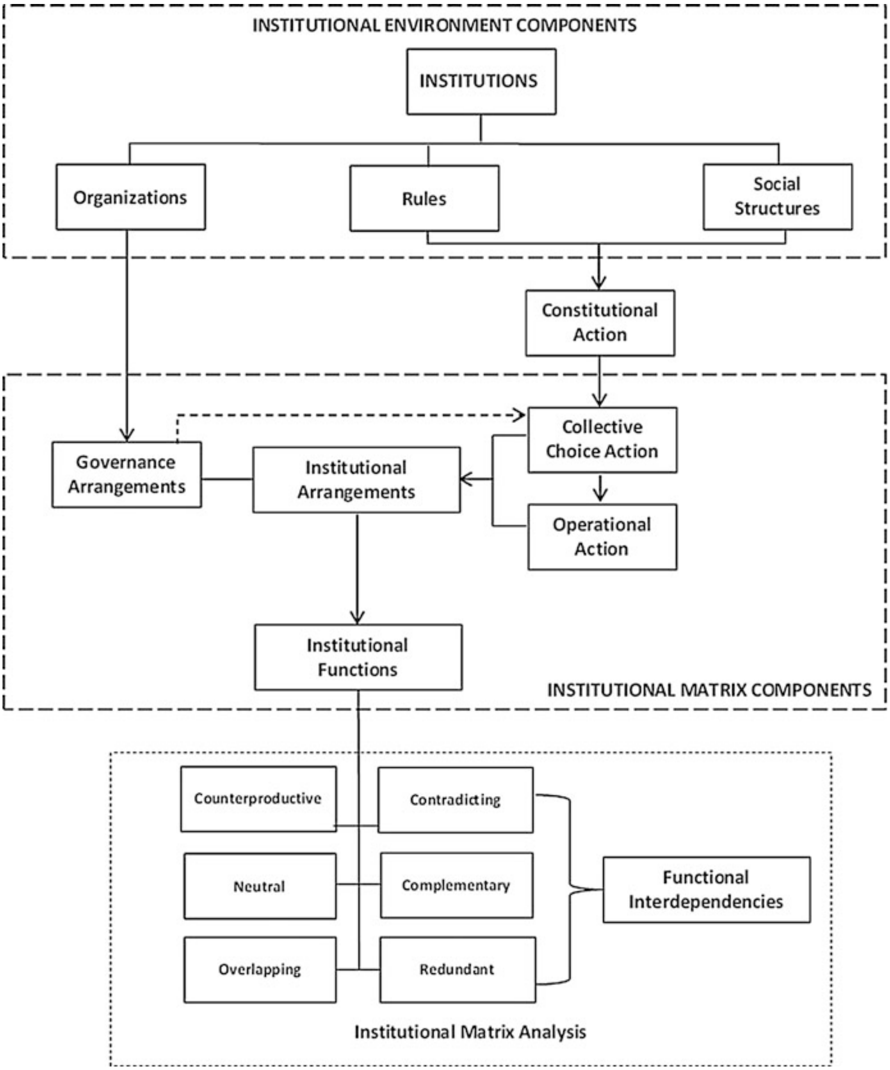

Fig. 4 Institutional environment matrix (IEM) framework (Source: Authors)

relationships among the institutions and assumes that institutions affect an adaptation response via the institutional arrangements that enable institutions to perform their functions.

The IE and the IM stages are closely linked, such that the IM is dependent on the information provided by the IE. This relationship, however, is one directional. Significant IE analyses can be done even without proceeding to the IM level, but the reverse is not possible.

Various institutional interactions, like complementary, neutral, and counterproductive relationships, are realized from the IM layer. Complementary interaction indicates beneficial associations such that institutions perform better because of the creation or existence of the other (Gunningham and Grabosky 1998). Conversely, counterproductive interactions result when institutional arrangements either destabilize or weaken one another, thus impeding the ability of institutions to perform their functions effectively. Neutral interaction suggests that institutions just simultaneously exist in the institutional environment without interacting with each other. The institutions neither improve nor worsen each other.

Contradicting relationships arise when institutions are mismatched, thereby creating situations in which institutional arrangements are not attuned with each other. This institutional linkage forms tensions and conflicts among institutions and the corresponding elements that function within these institutions (Nicholson-Cole and O'Riordan 2009). Overlapping associations involve disputes in jurisdictions (Davis 2006), especially when institutions have similar mandates (Aggarwal 2005). Institutional overlaps are common and more significant in a high-frequency institutional environment where there is a high density of institutional arrangements operating in a single system (Young 2002). Lastly, redundancy signifies complete duplication of all institutional functions (Fig. 3).

All the relationships, except redundancy, may exist in a single or multiple types of institutional functions. Policy 1 may be counterproductive with Policy 2 in establishing systems of power and authority but may be complementary in creating incentives for individual and collective actions. Likewise, there might not be any connection (neutral) between the two on defining information systems on climate change and adaptation. These linkages can be thoroughly examined using the institutional matrix analysis, which is further explained in the succeeding sections.

Institutional Environment (IE)

The IE layer (Table 3) is comprised of formal rules (FR), social structures (SS), formal organization (FO), and informal organization (IO). Formal rules represent the written laws, policies, and regulations, whereas social structures are the traditions, norms, and practices affecting social collective behaviors. This framework incorporates informal rules in the social structure-based institutions, following the notion that they are linked. Formal organizations are the groups legitimized by the formal rules, whereas the informal organizations are those sanctioned by informal rules. The institutions comprising the IE may have been created to address a variety of issues, some of which may not be related to climate change. These rules, social structures, and organizations have particular arrangements that can affect climate change adaptation decisions, hence their inclusion in the IE. Take the case of Carteret climate change refugees.[1] The adaptation response – community relocation – involves property institution and property right arrangements, both of which have been existing and working in the systems long before climate change concerns emerged.

Table 3 Institutional environment framework layout

Institutional systems: complex system/adaptation response	Institutional environment			
	Formal rules (FR)	Social structures (SS)	Formal organizations (FO)	Informal organizations (IO)
	FR1	SS1	FO1	IO1
	FR2	SS2	FO2	IO2
	FR3	SS3	FO3	
	FR4			

Source: Authors

In this hypothetical case (Table 3), the institutional framework identifies four formal rules (FR1, FR2, FR3, FR4); three social structures (SS1, SS2, SS3); three formal organizations (FO1, FO2, FO3); and two informal organizations (IO1, IO2) that affect the adaptation response. All types of institutions are included in this layer regardless of scale. For example, FR1 may be a national program, FR2 a regional regulation, and FR3 and FR4 local policies. This is possible because the IE layer assumes that the institutions existing in various scales may simultaneously affect (or be affected) by the same adaptation response(s) through their arrangements. These institutional arrangements cut across differing scales, and they structure the relationships and functional interdependencies of institutions. The arrangements associated with each institution are critical in determining the extent of the institution's influence in the decision-making process (Fig. 5).

For instance, the Environmental Protection Act 1994 (EP Act) – an act primarily concerned with environmental pollution in the state of Queensland, Australia – can influence local authorities' responsibilities and decisions. Though a state law, the EP Act specifies the responsibilities of local governments in notifying administering authorities of violations at the local level (EP Act, Part 8 [2]). (Commonwealth of Australia 1994).

Thus, the IE layer is composed of all institutions that may affect climate change adaptation, regardless of the scale at which the institution primarily operates. In contrast, the institutional matrix layer is limited to a single scale analysis – only those institutional arrangements that cover the scale (federal/national, state/regional/territory, provincial/local) being analyzed will be examined. In the previous hypothetical case (Table 3), while FR1 is a national program and FR2 is a regional regulation, only those arrangements affecting the local scale will be included in the matrix if the scale of analysis is local. These notions are further elaborated below.

[1]People were forced to leave their homes and resettle elsewhere because of climate change-related events.

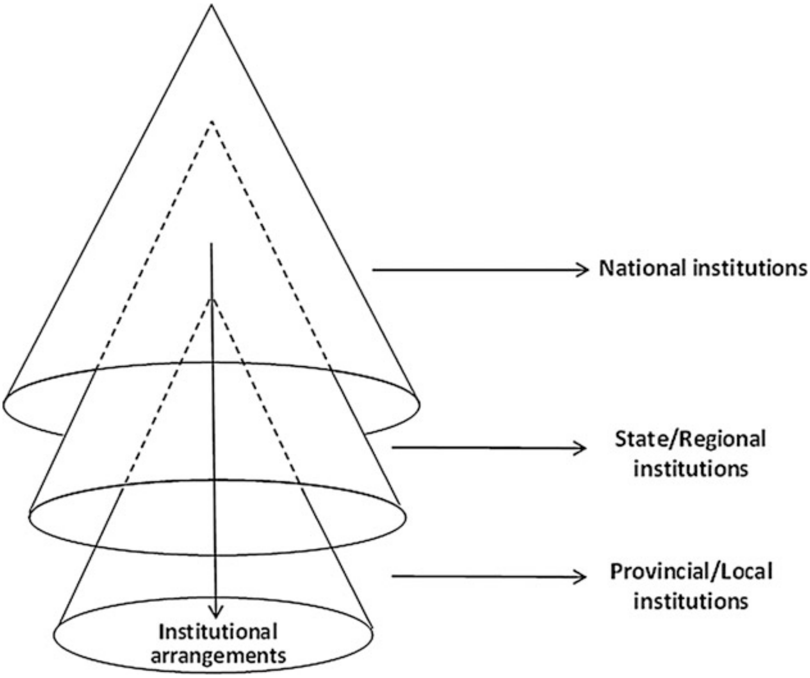

Fig. 5 Multilayered institutional linkages (Source: Authors)

Institutional Matrix (IM)

From the IE, the analysis progresses to the individual institutional arrangements in the institutional matrix (IM). The IM is dependent on the set of information provided by the IE stage, and those institutions identified in the environment are incorporated in the matrix (Table 4). In this hypothetical case, the IM analysis focuses on the local scale.

The functions are the source of interdependencies among institutions, which are vital elements of the IM layer. Institutional interplay is observed by analyzing the institutional arrangements that shape these functions. With this, the institutional functions compose the row headings, and they are the categories by which the institutional arrangements are organized in the IM cells.

Framework Analyses: Vertical and Horizontal

The framework offers two types of analyses – vertical and horizontal. Vertical analysis (Table 5) shows the influence of individual institutions on the adaptation response by examining each institution's function. As the hypothetical case has a local scale, only local arrangements will be included in the matrix. The vertical analysis of the formal rules indicates that the national program (FR1) incorporates

Table 4 Institutional matrix (IM): an institutional framework for adaptation analysis

FUNCTIONS OF AN INSTITUTION	TYPES OF INSTITUTIONS											
	Formal Rules (FR)				Social Structures (SS)			Formal Organizations (FO)			Informal Organizations (IO)	
	FR1	FR2	FR3	FR4	SS1	SS2	SS3	FO1	FO2	FO3	IO1	IO2
Reduces uncertainty												
Establishes systems of power and authority												
Identifies inclusions and exclusions												
Creates rights and entitlements												
Connects individuals to society												
Converts personal values into social norms and shared beliefs												
Influence and transforms individual acts and expectations into collective actions												
Creates (dis)incentives for individual and collective actions												
Coordinates individual or collective behaviors												
Fosters adaptive capacity												
Defines information systems												
Mediates influence of external interventions												
Mobilizes resource utilization												
Means of delivery of external resources												
Determines transaction costs of activities and decisions												

Notes: The function "creates rights and entitlements" does not apply to organizations, while the function "means of delivery of external resources" does not relate to formal rules and social structures. The cells are shaded accordingly.
Source: Authors

Table 5 Vertical analysis for formal rules

	Type of institution			
	Formal rules			
Functions of an institution	FR1	FR2	FR3	FR4
Reduces uncertainty				
Establishes systems of power and authority	✓	✓	✓	✓
Identifies inclusions and exclusions	✓	✓	✓	
Creates rights and entitlements			✓	
Connects individuals to society				
Converts personal values into social norms and shared beliefs				
Influences and transforms individual acts and expectations into collective actions	✓	✓	✓	✓
Creates (dis)incentives for individual and collective actions			✓	✓
Coordinates individual or collective behaviors	✓	✓	✓	✓
Fosters adaptive capacity				
Defines information systems	✓	✓	✓	✓
Mediates external interventions			✓	
Mobilizes resource utilization				
Means of delivery of external resources				
Determines transaction costs of activities and decisions		✓	✓	

Source: Authors

local arrangements that establish systems of power and authority, identifies inclusions and exclusions, influences and transforms individual acts and expectations into collective actions, coordinates individual or collective behaviors, and defines information systems. The regional regulation (FR2) performs the same tasks in addition to determining transaction costs of activities and decisions. The IM vertical analysis also outlines the dominant institution in the institutional environment. In the example, the local policy FR3 is the most influential among all four formal rules (Table 5).

An empty cell signifies that the institution does not perform the associated function at the specific scale in question. However, this does not imply that the institution does not implement the function at all. For example, FR1 may not create rights and entitlements at the local scale but may have such arrangements in either the national or regional scales. This aspect is the major difference between the IE and IM layers. Although cross-scale investigation is possible in the IE, this cannot be done in the IM. Overall, the vertical analysis shows the extent of the institution's influence on the adaptation response. It also compares its functions across institutions in a specific scale.

The horizontal analysis is more complicated as it studies the functional interdependencies of institutions and assesses the relationships across various institutions based on their functions. In the hypothetical case (Table 6), the institutional linkages of all 12 institutions are illustrated in relation to the function "establishes systems of power and authority." The cells in red are negative relationships,

Table 6 Horizontal analysis for structure power and authority system function

Establishes Systems of Power and Authority		Formal Rules				Social Structures			Formal Organizations			Informal Organizations	
		FR1	FR2	FR3	FR4	SS1	SS2	SS3	FO1	FO2	FO3	IO1	IO2
Formal Rules	FR1		Contradicting	Comple-mentary	Neutral	Comple-mentary	Counter-productive	Counter-productive	Neutral	Neutral	Neutral	Neutral	Neutral
	FR2	Contradicting		Counter-productive	Contradicting	Comple-mentary	Contradicting	Neutral	Comple-mentary	Contradicting	Comple-mentary	Counter-productive	Counter-productive
	FR3	Comple-mentary	Counter-productive		Overlapping	Neutral	Counter-productive	Neutral	Comple-mentary	Comple-mentary	Comple-mentary	Counter-productive	Contradicting
	FR4	Neutral	Contradicting	Overlapping		Neutral	Contradicting	Neutral	Contradicting	Contradicting	Neutral	Contradicting	Contradicting
Social Structures	SS1	Comple-mentary	Comple-mentary	Neutral	Neutral		Comple-mentary	Comple-mentary	Comple-mentary	Neutral	Contradicting	Comple-mentary	Comple-mentary
	SS2	Counter-productive	Contradicting	Counter-productive	Contradicting	Comple-mentary		Comple-mentary	Contradicting	Contradicting	Contradicting	Comple-mentary	Comple-mentary
	SS3	Counter-productive	Neutral	Neutral	Neutral	Comple-mentary	Comple-mentary		Neutral	Neutral	Neutral	Comple-mentary	Comple-mentary
Formal Organizations	FO1	Neutral	Comple-mentary	Comple-mentary	Contradicting	Comple-mentary	Contradicting	Neutral		Overlapping	Overlapping	Counter-productive	Comple-mentary
	FO2	Neutral	Contradicting	Comple-mentary	Contradicting	Neutral	Contradicting	Neutral	Overlapping		Overlapping	Comple-mentary	Neutral
	FO3	Neutral	Comple-mentary	Comple-mentary	Neutral	Contradicting	Contradicting	Neutral	Overlapping	Overlapping		Counter-productive	Counter-productive
Informal Organizations	IO1	Neutral	Counter-productive	Counter-productive	Contradicting	Comple-mentary	Comple-mentary	Comple-mentary	Counter-productive	Comple-mentary	Counter-productive		Overlapping
	IO2	Neutral	Counter-productive	Contradicting	Contradicting	Comple-mentary	Comple-mentary	Comple-mentary	Comple-mentary	Neutral	Counter-productive	Overlapping	

Source: Authors

specifically counterproductive and contradicting. Conversely, the green cells are positive associations, particularly the complementary type. Neutral and overlapping relationships are white and yellow, respectively. With regard to structuring power and authority systems, some of the possible interpretations of the matrix are as follows:

1. Formal rules generally have negative relationships with informal organizations.
2. Informal organizations are in harmony with the social structures.
3. Formal organizations typically have overlapping jurisdictions with one another.
4. Informal organizations typically have overlapping jurisdictions with one another.
5. Formal rules are generally counterproductive or contradictory to social structures.
6. The national program, FR1, has relationships only with social structures and other formal rules. It does not affect organizations, whether formal or informal.
7. The national program, FR1, contradicts with the regional regulation, FR2.
8. The national program, FR1, complements the local policy, FR3. As the national program and the regional regulation have a negative relationship, it is consistent that FR2 and FR3 are also contradicting each other. Thus, the regional regulation has a negative linkage with all other formal rules.
9. Local policies FR3 and FR4 overlap.
10. Both local policies are not attuned with the existing local norms, SS2, but are neutral to the local practices, SS1 and SS3.

Other assessments can be gleaned from this example. This type of analysis can be duplicated to the other functional classifications, thereby creating the overall assessment of the linkages between and among institutions. The matrix, thus, enables a planner or analyst to structurally examine complex institutional relationships, thus, possibly effectively evaluate and plan adaptation responses to climate change.

Conclusion

Institutions in climate change encompass rules, social structures, and organizations. The institutional dimension of climate change adaptation involves an intricate web of relationships between and among these institutions. In analyzing the complexity of institutions, a number of factors need to be considered such as institutional functions and interplay, as well as issues of scale (national, state, regional, and local) and jurisdiction. Thus, a purpose-built framework that can perform these kinds of analysis, such as the institutional environment matrix (IEM) framework, is needed.

The IEM adopts a dual-layered approach in examining the various institutions that directly or indirectly influence adaptation decisions and responses in a particular system. Institutions are intrinsically complex; hence a single layer analysis cannot cover the intricacies involved in an institutional analysis. Furthermore, this design allows institutions to be examined across scales and provides an easy transition toward a single scale analysis.

The dual layer design of the IEM allows the institutional environment and arrangements to be extensively studied. The IE layer includes all kinds of institutions in the environment regardless of scale, identifies the dominant institutions in the system affecting adaptation responses, and outlines the complexity of institutions in the institutional environment. Meanwhile, the IM layer enables a scale-focused analysis by dealing with particular institutional arrangements. The matrix allows for complex analysis of institutional linkages and interactions through the vertical and horizontal analytical approaches. By using these techniques, the functional interdependencies of institutions can be identified and institutional interplay can be explored.

The institutional dimension of climate change adaptation is motivated by the need to design or redesign arrangements to address the risks and impacts of climate change (Young 2002). Accordingly, the IEM framework helps identify whether the existing institutions hinder effective adaptation, especially when there are negative relationships among the institutional arrangements. This condition may warrant modifying or replacing the arrangements such that institutions will fit more effectively in the institutional environment. When new institutions need to be introduced into the system, the IEM framework may be useful in developing arrangements that will be compatible with the existing ones. This will help avoid mismatches among institutions and thus minimize conflicts.

This chapter has outlined a theoretical tool that can be used in adaptation planning and evaluation. However, the real value of the framework lies in its applicability in empirical cases. The need for further research in this area is vital.

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An Approach to Measure Vulnerability and Adaptation to Climate Change in the Hindu Kush Himalayas

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Abstract

In recent years the population of the Hindu Kush Himalayas (HKH) has been confronted with rapid social, economic, demographic, and political changes. In addition, the region is particularly vulnerable to climate change. However, there is a scarcity of cohesive information on the state of the environment and on the socioeconomic situation of the approximately 210 million people who reside in the HKH. Specifically, data on livelihood vulnerability and responsive behavior is lacking. To address this gap the International Centre for Integrated Mountain Development (ICIMOD) has developed the *Vulnerability and Adaptive Capacity Assessment* (VACA), a research tool to explore livelihood vulnerability to environmental and socioeconomic change as well as adaptive capacity in the mountain context. As part of the *Himalayan Climate Change Adaptation Programme* (HICAP), ICIMOD has carried out a representative quantitative survey that interviewed about 6,100 households in three sub-basins in the HKH region: the Upper Indus sub-basin in Pakistan, the Eastern Brahmaputra sub-basin in India, and the Koshi sub-basin in Nepal. The chapter discusses the operationalization of vulnerability in the VACA questionnaires, the research design of the VACA survey, and first findings for the three sub-basins.

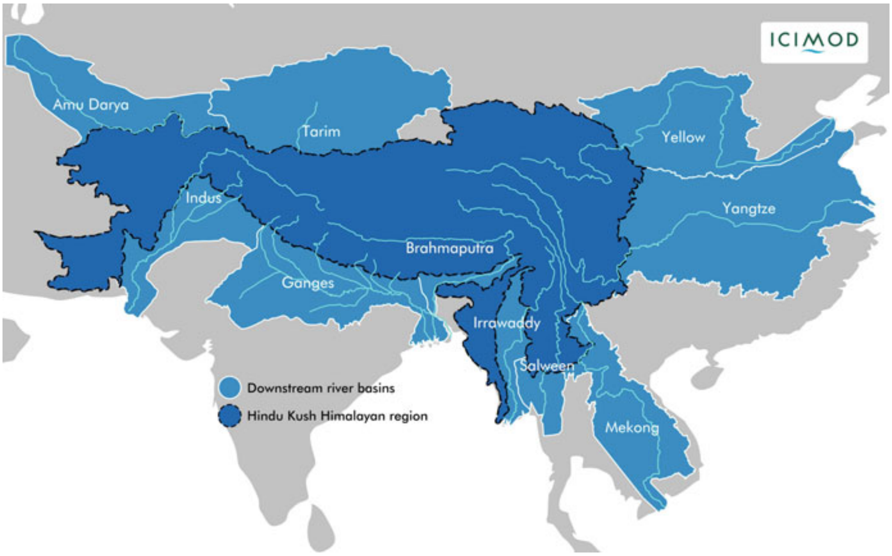
Keywords

Hindu Kush Himalayas • Climate change • Livelihood vulnerability assessment • Survey research

Introduction

The Hindu Kush Himalayan (HKH) region extends across parts of eight countries: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan (see Map 1). It is one of the poorest areas of the world: almost one-third of its approximately 210 million people lives below the absolute poverty line (Hunzai et al. 2011; Gerlitz et al. 2012). A significant proportion of mountain people reside in difficult terrains, far from the centers of commerce and power, and exert little influence over the policies and decisions that influence and shape their lives (Khalid and Kaushik 2008).

In recent years, the population of the HKH region has been confronted with rapid social, economic, demographic, and political changes. In addition, the region has experienced rapid environmental changes, and it is widely believed that the HKH region will be one of the planet's hot spots of future climate change impacts (Maplecroft 2011). Like other mountain regions, the Hindu Kush Himalayas have experienced above-average warming (IPCC 2007; Nogues-Bravo et al. 2007), which has led to glacial retreat, area reduction, and negative mass balance (Yao et al. 2012). The glaciers are important sources of water for springs and rivers, particularly during the dry season. The contribution of snowmelt to the runoff of major rivers varies from 10 % in the Eastern Himalayas to 60 % in the Western Himalayas (Vohra 1981). A modeling study by Immerzeel et al. (2010) simulated a



Map 1 The Hindu Kush Himalayan region (Source: ICIMOD)

mean decrease in upstream water supply between the periods 2000–2007 and 2046–2065 of 8.4 % for the Upper Indus, 17.6 % for the Ganges, 19.6 % for the Brahmaputra, and 5.6 % for the Yangtze. The cascading of effects from high- to low-altitude areas implies that impacts will be greater at lower elevations, e.g., increased runoff at high altitude could lead to floods and increased sand deposition on agricultural land at lower altitudes (Tse-ring et al. 2010). However, available studies are limited to isolated parts of the HKH region and may not be representative of the region as a whole (for detailed discussion of changes in temperature pattern for the Hindu Kush Himalayan region, see Eriksson et al. 2009; Xu et al. 2009; Shrestha and Devkota 2010). A lack of notable trends is observed in most of the precipitation studies in the HKH region (Shrestha et al. 2000; Shrestha 2009; Dimri and Dash 2011). In the Eastern Himalayas, climate change impacts are manifested in loss and fragmentation of habitat, reduction in forest biodiversity, degradation of wetland and riverine island ecosystems, decline in forage and fodder resources, reduction in agrobiodiversity, increase in forest fires, soil fertility degradation, changes in land use pattern, and increased variability in agricultural productivity (Tse-ring et al. 2010). Mountain communities and their livelihoods are sensitive to such changes, which will have a variety of impacts on human well-being. Nonetheless, there is a scarcity of data on the state of the environment in the Hindu Kush Himalayan (HKH) region, on the socioeconomic situation of its residents, and specifically on livelihood vulnerability to environmental and socioeconomic change and associated responsive behaviors. To address this gap, the International Centre for Integrated Mountain Development (ICIMOD) has developed the *Vulnerability and Adaptive Capacity Assessment* (VACA), a household survey to explore vulnerability and adaptive capacity in mountain contexts.

As part of the *Himalayan Climate Change Adaptation Programme* (HICAP), ICIMOD has carried out a representative quantitative study interviewing about 6,100 households of almost 280 settlements in three sub-basins in the HKH region: the Upper Indus sub-basin in Pakistan, the Eastern Brahmaputra sub-basin in India, and the Koshi sub-basin in Nepal. The aim of this survey was to assess livelihood vulnerabilities to environmental and socioeconomic changes, drivers of vulnerability, and the capacities of the people of the HKH region to adapt to these changes. It is intended that the VACA will help to identify and promote adaptation actions and strategies at the community level, enable the mapping of target areas and groups for interventions, and serve as a baseline for further in-depth studies.

The following sections describe the operationalization of vulnerability in the VACA questionnaires in the form of the Multidimensional Livelihood Vulnerability Framework for the HKH region, document the research design of the VACA survey in the three sub-basins, and discuss some first findings on exposure and coping mechanisms.

Theoretical Background: The Operationalization of Vulnerability in the VACA Tool

The Concept of Vulnerability

While the term "vulnerability" is used widely in development and adaptation contexts, there is no standard definition of vulnerability, and usage of the term varies considerably. Nonetheless, definitions of vulnerability tend to fall into two categories. The first category draws on the natural hazards literature and defines vulnerability as a function of the internal characteristics of a population or system that mediate the extent to which that population or system experiences harm as a result of exposure to an "external" *hazard* (Wisner et al. 2004). In this formulation, the risk of an undesirable outcome (e.g., a complex disaster) is a function of and results from the interaction of hazard and vulnerability. While this conceptualization of vulnerability may include local geographical and environmental factors that mediate risks/outcomes, it is strongly rooted in social and political processes and tends to take an actor-oriented approach (Wisner et al. 2004; Cannon and Müller-Mahn 2010; Miller et al. 2010). The vulnerability of a system to hazards associated with environmental change is linked with the wider political economy of resource use (Adger 2006). Generally, this approach tends to adopt socially defined scales, namely, household, community, and region (Miller et al. 2010).

The second category is associated to a large extent with the Third and Fourth Assessment Reports (TAR and AR4 respectively) of the Intergovernmental Panel on Climate Change (IPCC 2001, 2007), whose glossaries define vulnerability as:

> The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. (IPCC 2001, p. 995, 2007, p. 883).

Put more simply, the IPCC definition views vulnerability as a function of *exposure*, *sensitivity*, and *adaptive capacity* (Hahn et al. 2009). It differs from the natural hazards approach in viewing vulnerability as a function of both "internal" factors (sensitivity and adaptive capacity) *and* "external" factors (exposure to shocks and stresses). The latter are the various climate hazards associated with climate change and variability to which a system or population is exposed. The IPCC defines exposure as "the nature and degree to which a system is exposed to significant climate variations" (IPCC 2001, p. 987) and sensitivity as "the degree to which a system is affected, either adversely or beneficially, by climate related stimuli" (IPCC 2001, p. 993). Adaptive capacity is defined as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2001, p. 982).

In fact, the IPCC definition of vulnerability is structurally similar to the natural hazards definition of risk; the IPCC essentially replaces the term "risk" with "vulnerability" and the term "vulnerability" with sensitivity. The "character, magnitude, and rate of climate variation to which a system is exposed" takes the place of hazard, and the concept of adaptive capacity is added to address the fact that many manifestations and impacts of climate change will unfold over time-scales that are long enough for people to anticipate, plan for, and respond to these changes.

In its recent SREX report, the IPCC (2012, p. 32) defines vulnerability as "the propensity or predisposition to be adversely affected" and describes exposure and vulnerability as the determinants of risk. While the IPCC Fifth Assessment Report (AR5) has not been released at the time of writing, this suggests that the IPCC may be moving away from the definition of vulnerability in the glossaries of the previous two assessment reports and toward the more established natural hazards definition of vulnerability as a component of risk.

Nonetheless, this most recent IPCC definition of vulnerability is very vague. This may signify a desire on the part of the authors to accommodate multiple ways of defining and treating vulnerability, recognizing the diverse ways the concept has been used in the climate change literature, without contradicting the earlier IPCC glossary definition.

For the operationalization of vulnerability in the VACA questionnaire, the definition in the glossaries of the IPCC TAR and AR4 is used. This definition has been widely adopted and has been used to frame a growing number of studies that range from local-scale studies with the unit of analysis being the household (Eakin and Bojórquez-Tapia 2008; Pandey and Jha 2011; Notenbaert et al. 2012; Sonwa et al. 2012) to global-scale studies that examine the relative vulnerability of individual countries (Yohe et al. 2006a, b; Allison et al. 2009). Other studies apply this approach at the national or subnational scale to analyze the relative vulnerability of individual states or districts (O'Brien et al. 2004; Brenkert and Malone 2005; Malone and Brenkert 2008). Common to all these definitions are the key concepts of exposure, sensitivity, and adaptive capacity (Miller et al. 2010). While recognizing the diverse and evolving definitions of vulnerability in the literature, the authors choose to use the widely recognized IPCC TAR/AR4 definition, reflecting its widespread adoption by researchers and practitioners in recent years.

Mountain Specificities

Mountain regions are characterized by a variety of specific features that have to be taken into account if one wants to measure vulnerabilities in the HKH region. These *mountain specificities* on the one hand enable human activities and on the other constrain such activities (Jodha 1992, 1997, 2001; Körner et al. 2005). "Enabling features" include a high diversity of resources, species, and cultures, as well as diverse niches for specific livelihood activities and products, associated with a great range of human adaptations. "Constraining factors" include environmental and social fragility, marginality, and limited accessibility. Within the mountain specificities framework, inaccessibility captures all elements of distance and mobility as well as the availability of risk management options. Marginality is defined as the lack of social and political capital, which often results in difficulties in securing tenancy rights over land and in gaining access to social services such as credit, education, and health. Fragility is understood as the diminished capacity of a social or ecological system to manage shocks. The social dimensions of fragility in the mountains occur due to scarce, scattered, and periodically unavailable livelihood resources. Ecological fragility is linked with low carrying capacities coupled with topography (slope and relief). On the other hand, the concepts of diversity, niche, and adaptive capacity seek to capture different coping abilities and strategies that emerge from the natural resource management patterns, livelihoods, and cultural practices of a given community.

Mountain areas are challenging and demanding living spaces, and mountain communities have a long history of adapting to extreme conditions. Nonetheless, traditional adaptation mechanisms are often insufficient to cope with recent socioeconomic and environmental changes (Jodha 1997), which have considerably increased the challenge for mountain people to secure their livelihoods (O'Brien and Leichenko 2000). In developing countries, economic development in mountain regions already lags behind that of lowlands, foothills, and urban areas (Tanner 2003; Barrera-Mosquera et al. 2010). Climate change is expected to exacerbate existing challenges faced by mountain people and their environments, to intensify some existing hazards, and to result in the emergence of new hazards (Sonesson and Messerli 2002; O'Brien and Leichenko 2000; Macchi and ICIMOD 2010). These processes will intensify the exposure component of vulnerability. The sensitivity component will include environmental aspects embedded in the biophysical features of a region and social elements that are closely linked to the nature and range of available livelihood options (Jodha 1997) as well as the access to resources (Adger and Kelly 1999; Brooks and Adger 2005; Macchi et al. 2011).

The Multidimensional Livelihood Vulnerability Framework for the HKH Region

For the operationalization of vulnerability in the VACA questionnaire, the authors follow the precedent established by a number of recent studies, as discussed above, and use a framework based on the established IPCC definition of vulnerability, in which vulnerability is defined as a function of *exposure*, *sensitivity*, *and adaptive capacity* (IPCC 2007), the relationship between which is defined as follows:

$$\text{Vulnerability} = f\,(\text{Exposure} + \text{Sensitivity} - \text{Adaptive capacity})$$

Within this framework, the authors use household-level indicators to capture key socioeconomic drivers of sensitivity, aspects of adaptive capacity, and the extent to which households have been exposed in recent years to evolving environmental hazards that are likely to be influenced by climate change, as well as socioeconomic hazards. Sensitivity is viewed as a factor that makes people or systems more likely to experience harm when exposed to a hazard or stress (i.e., the focus is on the negative aspects of sensitivity, with any “positive” aspects of sensitivity that allow people to recognize and respond to changes in a timely manner being associated with adaptive capacity). Adaptive capacity is a quality that allows people and systems to increase their ability to cope with external (e.g., climate) stresses and hazards and to expand the range of conditions under which they can sustain themselves and their livelihoods. Adaptive capacity thus reduces vulnerability to hazards that recur or unfold over periods of sufficient duration to allow people and systems to respond and adapt to change (Brooks 2003).

To estimate the vulnerability of a “system” (e.g., an individual, household community, district, or country), it is necessary to identify the factors that contribute to the three elements of exposure, sensitivity, and adaptive capacity and capture these factors using indicators. These indicators can then be combined to create a composite vulnerability index.

Here the authors build on the methodology developed by Hahn et al. (2009), who developed a *livelihood vulnerability index (LVI)* that focuses on quantifying the strength of current livelihood systems and the capacity of communities to alter livelihood strategies in response to climate-related exposures. The LVI combines the sustainable livelihoods approach (Chambers and Conway 1992; Scoones 1998) with the measurement of vulnerability as defined by the IPCC. Rather than taking a model-driven, impacts-based approach to the measurement of vulnerability, the LVI uses primary data from household surveys. The LVI consists of seven major components: sociodemographic profile, livelihood strategies, social networks, health, food, water, natural disasters, and climate variability. Each of these major components comprises a number of indicators or subcomponents and is associated with one of the elements of vulnerability (i.e., exposure, sensitivity, or adaptive capacity).

This LVI framework has been adapted to a mountain context for application to the HKH region, reflecting the need to address the *mountain specificities* discussed.

The resulting Multidimensional Livelihood Vulnerability Framework for the HKH region (MLVF-HKH) incorporates indicators that are relevant in mountain contexts, such as physical accessibility, environmental stability, and social networks which refer to the constraining characteristics inaccessibility, fragility, and marginality. It also addresses the fact that climate change will not act in isolation from other stresses by taking into account economic shocks (e.g., unemployment or the failure of a business). The MLVF-HKH forms the basis of the VACA questionnaire. To operationalize the MLVF-HKH, its subdimensions were broken down into measurable indicators. These indicators are captured by specific questions within the VACA questionnaires. Table 1 gives an overview of the main dimensions, subdimensions, and indicators of the MLVF-HKH.

Research Design: The Implementation of the VACA Survey

The Survey Instrument

The *Vulnerability and Adaptive Capacity Assessment* (VACA) research tool consists of a settlement and a household questionnaire. The *Multidimensional Poverty Assessment Tool* (MPAT), created by IFAD (see Cohen 2009), provided a conceptual basis for the development of these questionnaires, while the structure and content of the questionnaires is based on the MLVF-HKH described above. The VACA questionnaires also incorporate elements from the *Vulnerability Assessment Mapping* (VAM) survey created by the World Food Programme (WFP) and the *Nepal Living Standard Survey* 2002/2003 (NLSS). These elements provide the questions for the sections on household food and nonfood consumption and accessibility, respectively. The thematic areas covered by the VACA include household consumption, food security, water security, health and health care, access to basic facilities, accessibility, housing, education, assets, exposure to shocks, medium-term climatic and environmental changes, and coping behavior. The VACA questionnaires were piloted by local partner institutions in India, Nepal, and Pakistan. Feedback was used to tailor the tools to local contexts and the practical requirements of surveys.

Study Site Selection

The Himalayan Climate Change Adaptation Programme (HICAP) focuses on the three major river basins of the HKH: the Indus basin, the Ganges basin, and the Brahmaputra basin. The three basins were selected based on expected significant impacts that climate change will have there. The selected basins show different degrees of dependency on meltwater from snow and glaciers (Vohra 1981), which is crucial if one wants to analyze the impact of global warming on snow and glaciers as well as the associated downstream implications.

Table 1 Multidimensional Livelihood Vulnerability Framework: dimensions, subdimensions, and indicators

Main dimensions	Subdimensions	Indicators
Adaptive capacity	Sociodemographic status	Dependency ratio
		Educational attainment of HH head
	Access to resources	Agricultural land per head
		Livestock per head
	Livelihood strategies	Primary sector livelihood diversity
		Secondary and tertiary sector livelihood diversity
		Yearly amount of remittances per head
		Cash crops diversity
	Social networks	Political influence on the local level
		Ease to borrow money
	Physical accessibility	Time to reach the next market center
		Time to reach the next hospital
		Time to reach the next bus stop
Sensitivity	Well-being	Total per head consumption
		Communication and transport assets
		Affordability of health care
		Extent of indebtedness
	Health and sanitation	Frequency of serious illnesses
		Access to improved sanitation
		Access to improved source of drinking water
		Perceived quality of drinking water
	Food security	Food self-sufficiency
		Months HH had sufficient food
		Food crops diversity
		Diet diversity
	Water security	Time to reach primary water source
		Months of water sufficiency for HH needs
		Severity of water conflicts
		Months of water sufficiency for crops and livestock
	Coping strategies	Short-term livelihood diversification coping strategies implemented
		Average time to recover from shocks in relation to combined severity
		Medium-term coping strategies implemented
	Environmental stability	Majority of agricultural land flat or sloping
		Majority of agricultural land irrigated land
		Quality of soils of majority of land
		Quality of wall material of dwelling
		Degree to which dwelling can withstand extreme weather events

(*continued*)

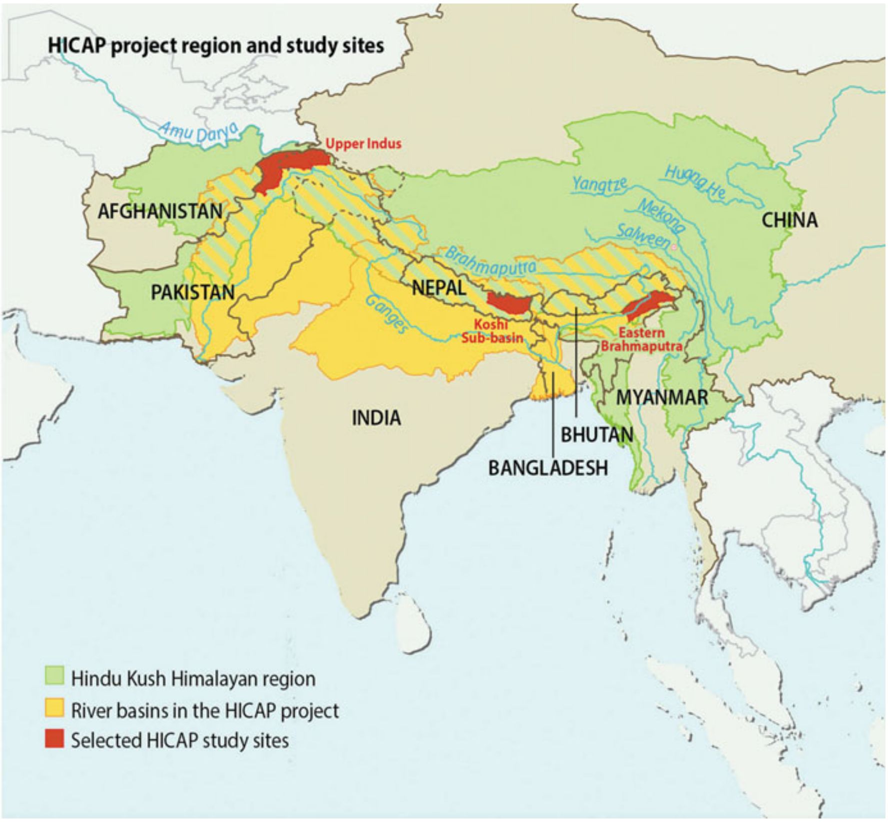
Table 1 (continued)

Main dimensions	Subdimensions	Indicators
Exposure	Short-term exposure	Environmental shocks during the past 12 months
		Combined damage in US$ caused by environmental shocks during the last 12 months
		Socioeconomic shocks during the past 12 months
		Combined damage in US$ caused by socioeconomic shocks during the last 12 months
	Medium-term exposure	Perceived change in frequency of certain climatic events over the last 10 years
		Perceived change in severity of certain climatic events over the last 10 years
		Perceived new climatic or environmental conditions over the past 10 years
		Perceived change in temperature over the past 10 years
		Perceived change in precipitation over the past 10 years

Within the three river basins, sub-basins were selected based on the following criteria: (1) representativeness of the HKH region, (2) availability of data (gauging stations, secondary data, etc.), (3) population density (vulnerable communities), (4) accessibility, and (5) land use pattern. Out of six potential sites, the VACA was conducted in the following three sub-basins: the Upper Indus sub-basin in Pakistan, the Koshi sub-basin in Nepal, and the Eastern Brahmaputra sub-basin in India (see Map 2).

Sample Design

The selection of households for VACA data collection within the three sub-basins followed a three-staged random sampling procedure. In the first step, there was a purposeful selection of districts within the sub-basins based on the following seven criteria: (1) a substantial proportion of land that can be characterized as hilly or mountainous (some plain and foothill district areas were selected as a control group); (2) prior environmental hazards such as floods, flash floods, or droughts; (3) representativity in terms of ecological, ethnic, livelihood, and socioeconomic aspects; (4) expected vulnerability to future climate change impacts; (5) being part of the HICAP feasibility study (2009–2010); (6) availability of operational partners to conduct the VACA survey; and (7) the security situation and accessibility. Expert opinions from ICIMOD, regional research institutes, and local partner institutions were sought for the final selection. In the second step, a random selection of settlements within the selected districts took place. In the third step, there was a random selection of households within the settlements. One enumerator from each survey team was asked to stand in the center of the settlement and randomly select a direction for the first interview. The other interviewers were asked to start from the



Map 2 The VACA study sites (Source: ICIMOD)

periphery of the settlement and progress in a random direction. The enumerators walked in the respective directions, counting houses until they reached a prior given number. This was the first house to be surveyed. If a household was empty, then the enumerator moved to the next closest household. This procedure was continued until the quota for the settlement was accomplished. In each selected district, the sample size required to ensure representativity at district level was surveyed – in many cases approximately 385 households. The number of households surveyed per settlement was proportional to the total population. Overall, 6,096 households of 279 settlements were interviewed. Table 2 presents the details of the samples in India, Nepal, and Pakistan.

Field Work

VACA survey fieldwork was undertaken between October 2011 and April 2012. In Pakistan, the interviews were conducted from October until mid-November 2011.

Table 2 VACA sample size by country, state, and district for India, Pakistan, and Nepal

Sub-basin (country)	State/province/ development region	District	Sample size (HH)	Sample size (settlement)
Eastern Brahmaputra (India)	Arunachal Pradesh	East Siang	375	23
		Lower Dibang	380	19
		Lohit	330	20
	Assam	Dhemaji	390	20
		Lakhimpur	390	20
		Marigaon	386	14
		Tinsukia	396	18
	Total		2,647	134
Upper Indus (Pakistan)	Khyber Pakhtunkhwa	Chitral	383	10
	Gilgit-Baltistan	Hunza-Nagar	376	12
		Gilgit	380	5
	Total		1,139	27
Koshi (Nepal)	Central Mountains	Dolakha	385	18
	Central Hills	Kavrepalanchowk	385	16
	Eastern Hills	Khotang	385	18
		Udaipur	385	24
	Eastern Terai	Sunsari	386	18
		Siraha	384	24
	Total		2,310	118

The data collection was done in collaboration with the Aga Khan Support Programme (AKRSP). In India, data were collected between November 2011 and end of March 2012 in collaboration with Aaranyak. In Nepal, the survey was conducted from December 2011 to February 2012. Here, the data collection was done in collaboration with the Nepal Development Research Institute (NDRI) and the Koshi Victim's Society (KVS). Each field team consisted of the enumerators, field supervisors, and a local coordinator. The enumerators were responsible for conducting the interviews. The field supervisors oversaw the work of the enumerators, provided clarifications, checked completed questionnaires, and managed local logistics. The local coordinator managed the implementation of the VACA in the respective sub-basins.

The VACA implementation comprised the following generic steps: an orientation and training session, pre-survey preparation, settlement and household survey, post-survey revisit, and data entry and compilation. Orientation and training were conducted separately in each of the sub-basins. These sessions involved discussions with the field team on issues such as objectives of the study, research design, sampling method, survey technique, ethics, confidentiality protocol, and questionnaires. Where survey questions contained technical terms which did not have synonyms in the local language, the entire field team agreed upon a common definition. The training session included test interviews in villages, which were supervised by the field supervisors. The training sessions were followed by debriefing sessions to collect feedback from enumerators, field supervisors, and local coordinators and provide clarification.

Prior to the field work, the field teams briefed the community elders or villages leaders about the aim and content of the study. As VACA required detailed information about various aspects of a household, original survey protocol required that interviews should be conducted with the functional head of the household, irrespective of the person's age or gender. The enumerators explained the objectives of the survey to the respondent and obtained a verbal consent before continuing with the interview. An interview was left incomplete if the respondent refused to provide the verbal consent. The enumerator recorded the refusal and moved to the next closest household. In the case of the settlement questionnaire, the head or a senior member of a rural or urban public institution was interviewed.

On average, a household interview required 1 h and 20 min, ranging from 30 min to two and a half hours. The interviews were conducted in the primary local language of the sub-basin. The completed questionnaires were collected and random plausibility checks were carried out by the field supervisors. In cases of discrepancies, enumerators revisited particular households to seek clarifications. The household and settlement questionnaires were entered in a data entry mask. After entering the data, plausibility checks were performed to control for entry errors and inconsistencies to guarantee the quality of the data.

Challenges in the Field

Several challenges were encountered during the implementation of VACA. People in the HKH region generally associate the collection of data with imminent development interventions. Such perceptions can create expectations of forthcoming benefits in return of their participation. Prior to the interviews, enumerators told the respondents and community elders that VACA would not lead to any immediate direct development intervention. They pointed out that since the tool captures significant issues of the household and the community, the study will contribute to more informed policy and development planning at various levels.

The spatial and temporal synchronization of the survey proved to be a challenge. In some study areas, the process was delayed because of adverse weather, the farming cycle, availability of enumerators, and sensitive security situations. Due to cultural sensitivities and general curiosity among people in the communities, it was difficult to conduct one-on-one interviews with female respondents. Often, the female respondent was surrounded by men, women, or children from the same household or neighborhood. Under such circumstances, the respondents were often reluctant to respond frankly to culturally sensitive issues. Sometimes, onlookers tried to influence the respondent's opinion. The presence of female enumerators was able to resolve this to a limited extent.

First Findings of the VACA Survey

Methods

The following analyses were based on VACA household data from India, Nepal, and Pakistan. The findings consist of weighted descriptive analyses of basic indicators for short-term and medium-term exposure as reported by the surveyed households, and the identification of coping strategies deployed to deal with the stresses to which these households were exposed. The presented percentages and means were differentiated by sub-basin.

Short-term Exposure and Coping Strategies

One section of the VACA questionnaire deals with short-term exposure to environmental and socioeconomic shocks as well as coping behavior applied by the households to deal with the events mentioned. Figure 1 presents the three most common environmental shocks during the last 12 months prior to the interview that households of the three sub-basins reported. In both areas water-related events seem to have played a significant role: on the one hand people faced too much water in the form of floods in the Upper Indus sub-basin and Eastern Brahmaputra sub-basin[1] (19 % and 17 %, respectively). On the other hand there was too little water which resulted in droughts in the Eastern Brahmaputra sub-basin (16 %) and irrigation problems in the Koshi sub-basin (22 %). A considerable number of the households of the Koshi and Upper Indus sub-basins reported erratic rainfall (16 % and 14 %, respectively). In addition to water-related stresses, a significant percentage of households in the three sub-basins had to deal with livestock diseases (32 % in Eastern Brahmaputra, 22 % in Koshi, and 11 % in Upper Indus).

The three most common socioeconomic shocks which were reported by the households are shown in Figure 2. It becomes apparent that people of all the surveyed sub-basins were confronted with quite similar socioeconomic problems, although to a different extent. In all three areas family sickness was the most common socioeconomic stressor (63 % in Eastern Brahmaputra, 43 % in Koshi, and 36 % in Upper Indus), followed by electricity shortage (38 %, 33 %, and 32 %, respectively). In addition, debts were one of the frequently mentioned socioeconomic problems both in the Koshi sub-basin and in the Eastern Brahmaputra sub-basin (30 % and 16 %, respectively), while about seven percent of the households in the Upper Indus sub-basin were confronted with poor access to markets.

[1]The authors would like to emphasize that the presented information was obtained by the respondents. In the reference period, neither local nor national authorities have declared a drought in the Eastern-Brahmaputra sub-basin.

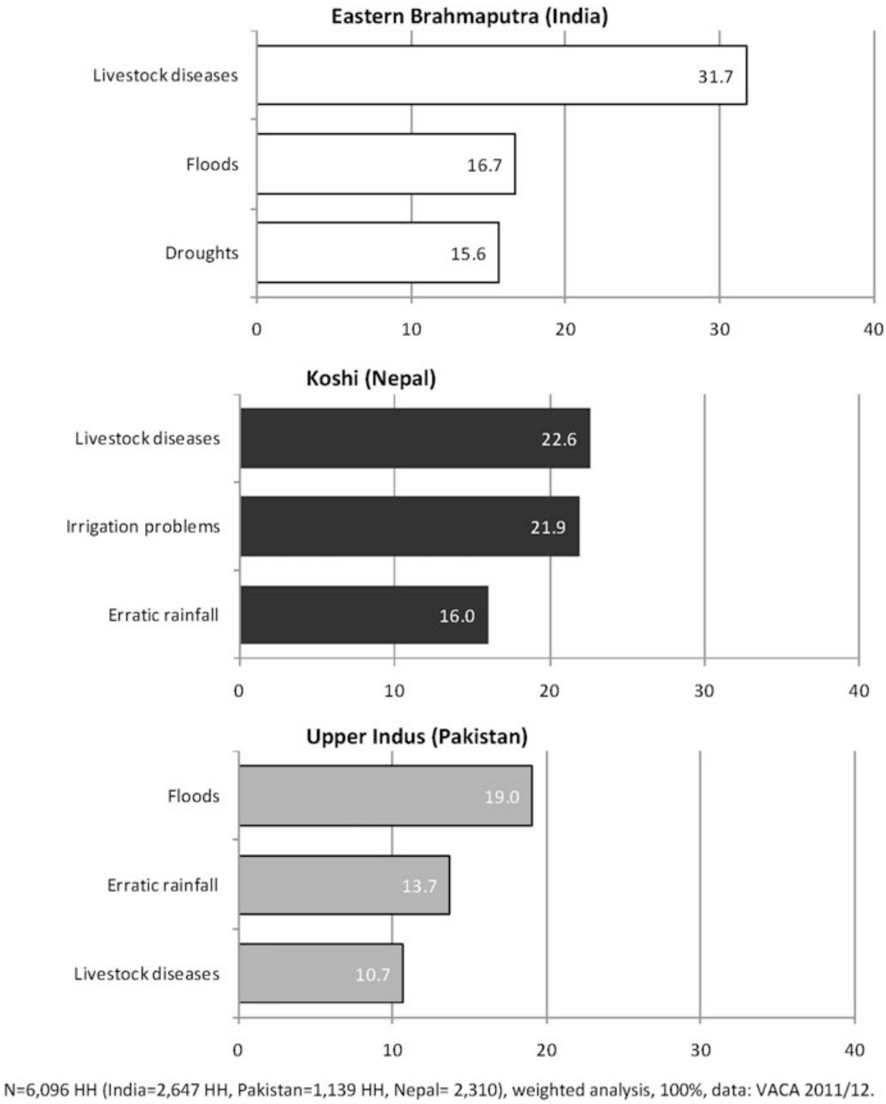
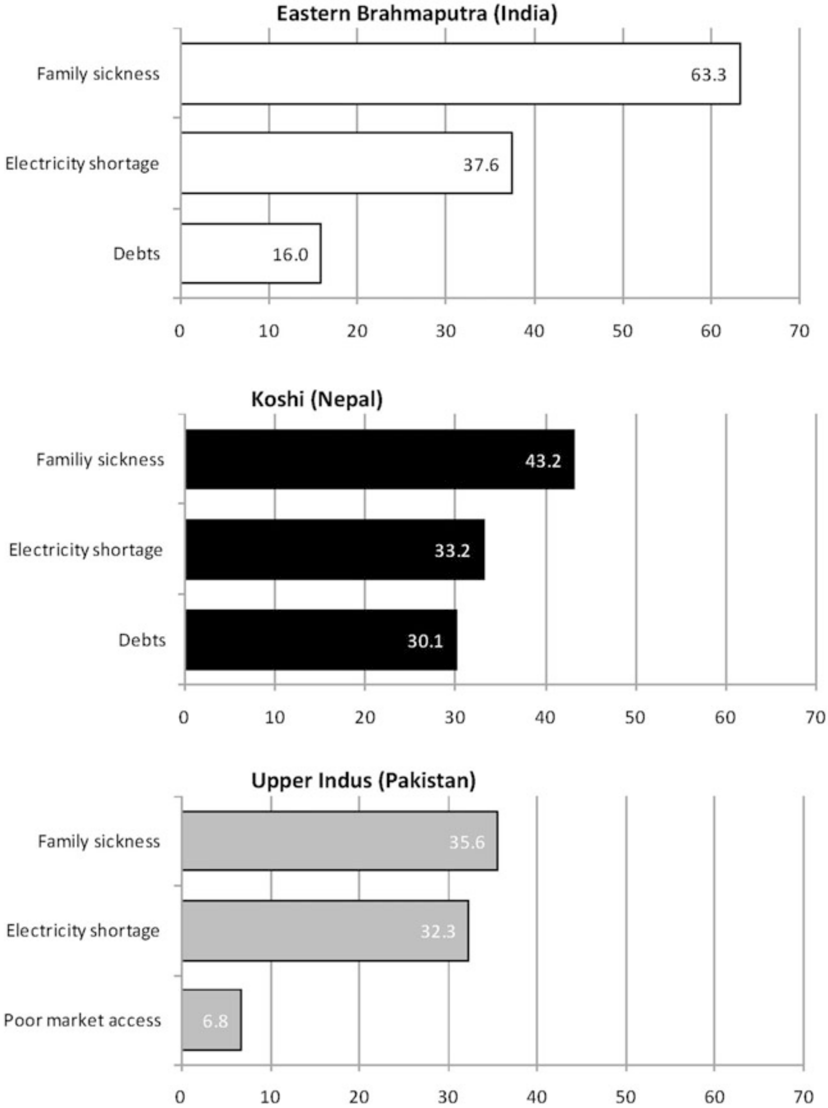


Fig. 1 The three most common environmental shocks during the last 12 months by sub-basin (in % of HH)

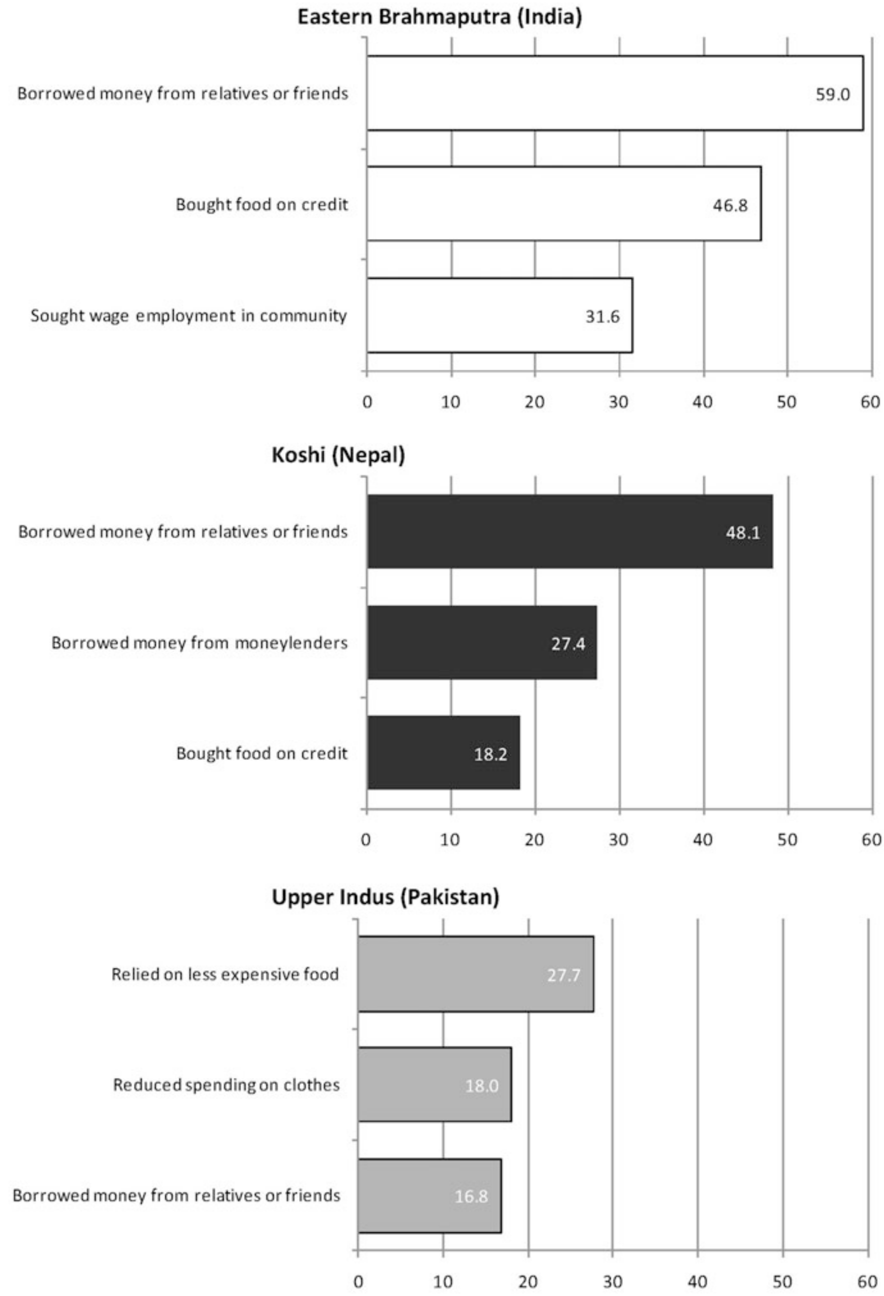
The VACA questionnaire records a broad variety of strategies employed by households to cope with short-term exposure. Figure 3 presents the three most common coping strategies that were reported by the people of the three sub-basins. One of the basic strategies to cope with short-term shocks that households of all three sub-basins applied was borrowing money from relatives or friends (59 % in Eastern Brahmaputra, 48 % in Koshi, and 17 % in Upper Indus). In addition,



N=6,096 HH (India=2,647 HH, Pakistan=1,139 HH, Nepal= 2,310), weighted analysis, 100%, data: VACA 2011/12.

Fig. 2 The three most common socioeconomic shocks during the last 12 months by sub-basin (in % of HH)

one-fourth of the people of the Koshi sub-basin have taken loans from money-lenders (27 %). A significant percentage of households of the Indian and Nepalese sites reported that it has bought food on credit (47 % and 18 %, respectively), which is just another form of borrowing money. It can be assumed that this



N=5,855 HH (India=2,571 HH, Pakistan=985 HH, Nepal= 2,299), weighted analysis, 100%, data: VACA 2011/12.

Fig. 3 The three most common coping strategies to deal with shocks by sub-basin (in % of HH) type of coping is related to the indebtedness which is one of the major socioeconomic problems reported by the households of the Koshi and Eastern Brahmaputra sub-basins. In the Upper Indus sub-basin, the reduction of spending on basic goods like food (28 %) and clothes (18 %) is another relevant coping strategy. In the Eastern Brahmaputra sub-basin, almost one-third of the households reported that they have sought wage employment to deal with short-term exposure.

Medium-term Exposure and Coping Strategies

The VACA questionnaire includes a section for recording medium-term exposure, i.e., perceived environmental and climatic changes during the 10 years prior to the survey. Figure 4 shows the percentage of households that has observed changes in their environment as well as in temperature and precipitation patterns, differentiated by sub-basin. Almost all households of the Upper Indus sub-basin reported that they have experienced changes in all of the three aspects. Though the respective percentages in the Eastern Brahmaputra sub-basin and the Koshi sub-basin are significantly lower, still a broad majority has observed environmental and climatic changes.

If households reported that they have experienced changes, they were asked to describe the changes that they have perceived. This was done separately for changes in the environment, changes in temperature patterns, and changes in

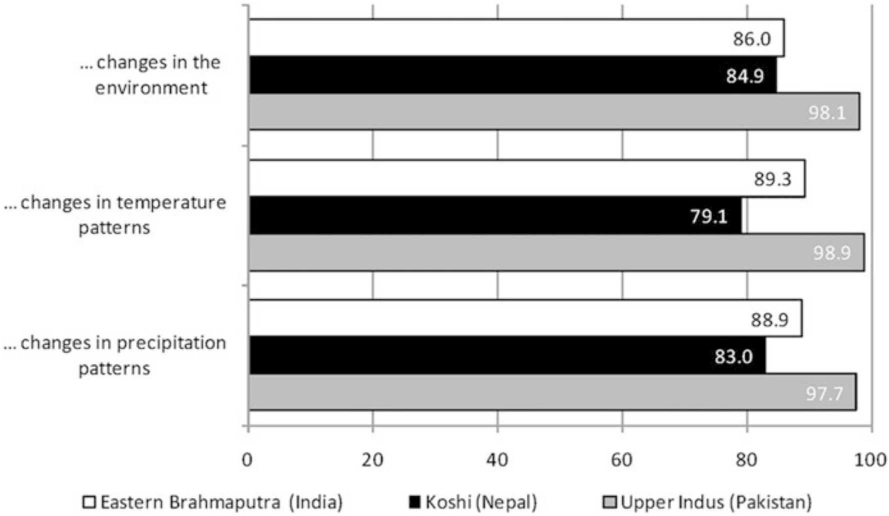


Fig. 4 Households which have observed the following changes over the last 10 years by basin (in % of HH) N = 6,094 HH (India = 2,646, Pakistan = 1,139 HH, Nepal = 2,309), weighted analysis, 100 %, data: VACA 2011/12

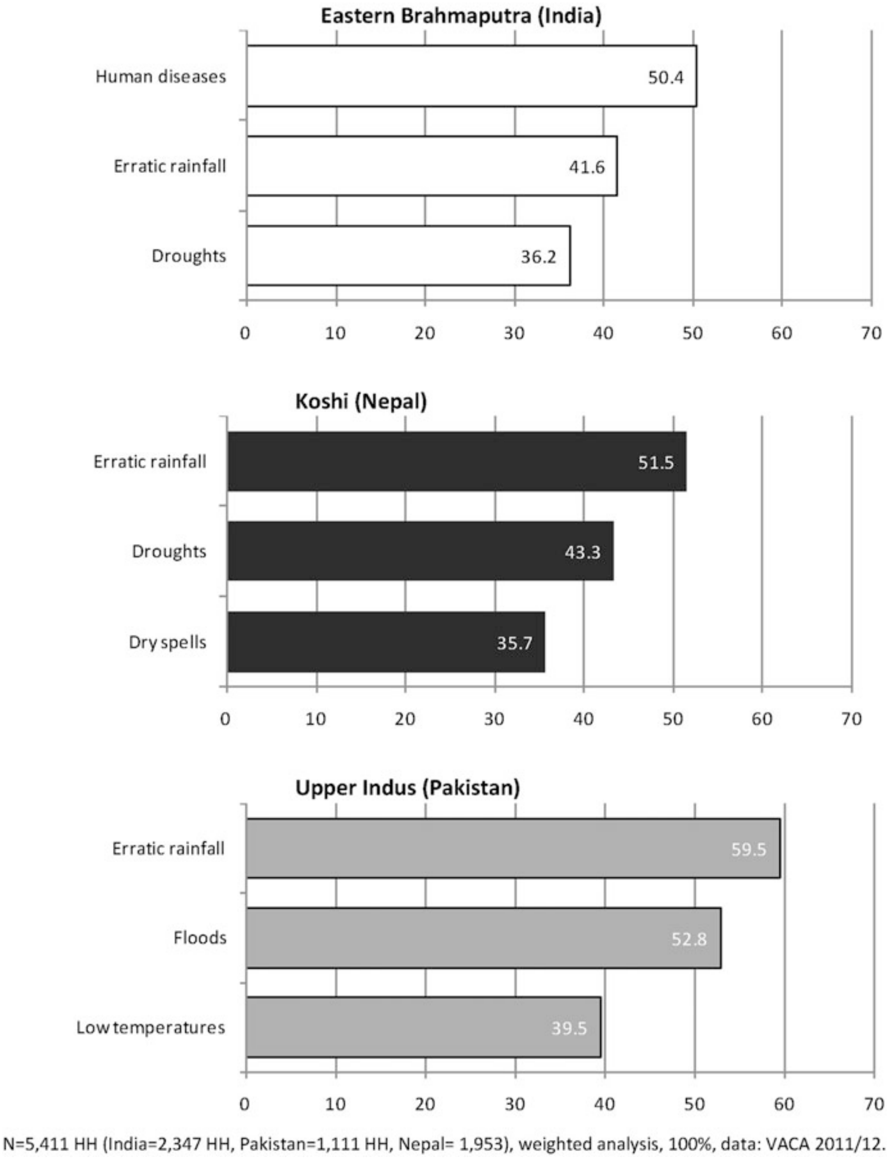


Fig. 5 The three most common new events observed in the environment over the last 10 years by sub-basin (in % of HH)

precipitation patterns. Figure 5 illustrates the three most commonly reported new environmental stressors during the last 10 years. Again, several of the stressors were water related: too much water in the form of floods in the Upper Indus sub-basin (53 %) and too little water in the form of droughts (43 % in Koshi, 36 % in Eastern Brahmaputra)[2] and dryspells (36 % in Koshi). In addition, a significant percentage of households in the three sub-basins reported erratic rainfall (60 % in Upper Indus, 52 % in Koshi, and 42 % in Eastern Brahmaputra). Irrespective of water-related stressors, a large number of households in Upper Indus have observed extraordinary low temperatures over the last 10 years (40 %). It should be pointed out that the most frequent new event reported by the people of the Eastern Brahmaputra sub-basin were human diseases (50 %).

Figure 6 shows the three most common strategies employed by households to cope with new environmental and climatic conditions over the last 10 years. Overall, the percentage of households in Nepal reporting that they have applied any coping strategy is lower than in Pakistan and India. People of all three sub-basins applied quite similar measures: a primary strategy in all three sub-basins was giving up planting certain kinds of crops (28 % in Upper Indus, 22 % in Eastern Brahmaputra, and 17 % in Koshi). In the Upper Indus sub-basin and the Koshi sub-basin one of the most common practices was to change farming practices (28 % and 12 %, respectively), i.e., bringing forward or delaying sowing and harvesting. In the Koshi sub-basin and the Eastern Brahmaputra sub-basin, a significant percentage of households introduced new crops and varieties (15 % and 11 %, respectively). Apart from farm-related coping strategies, in the Eastern Brahmaputra sub-basin almost one-fourth of the households took on new off-farm activities to deal with medium-term exposure.

Discussion

Because of the limited availability of historical time series data on temperature and precipitation in the HKH region and the marked microclimatic variation in altitude and aspect (Singh et al. 2011), a direct comparison of perceptions of climatic medium-term exposure in the three sub-basins with hydrometeorological data is difficult. Available climate data indicate a moderate warming, while data on precipitation do not show any statistically significant trends. Climate models for the region generally predict increasing temperatures and greater amounts of precipitation than at present to the middle of the century (Singh et al. 2011). Nevertheless, people's perceptions can be useful as proxies for missing climate data at the local level and as a supplement for scientific data (Macchi et al. forthcoming).

In all three sub-basins, perceptions of climatic and environmental short-term and medium-term exposure are mainly water related. Unpredictable precipitation and changes in water availability have direct impacts on primary sector activities which make up a large part of the livelihoods of the population of the study sites. Changes in precipitation timing (e.g., changes in the onset of summer and winter monsoon)

[2]The authors would like to emphasize that the presented information was obtained by the respondents. In the reference period, neither local nor national authorities have declared a drought in the Eastern-Brahmaputra sub-basin.

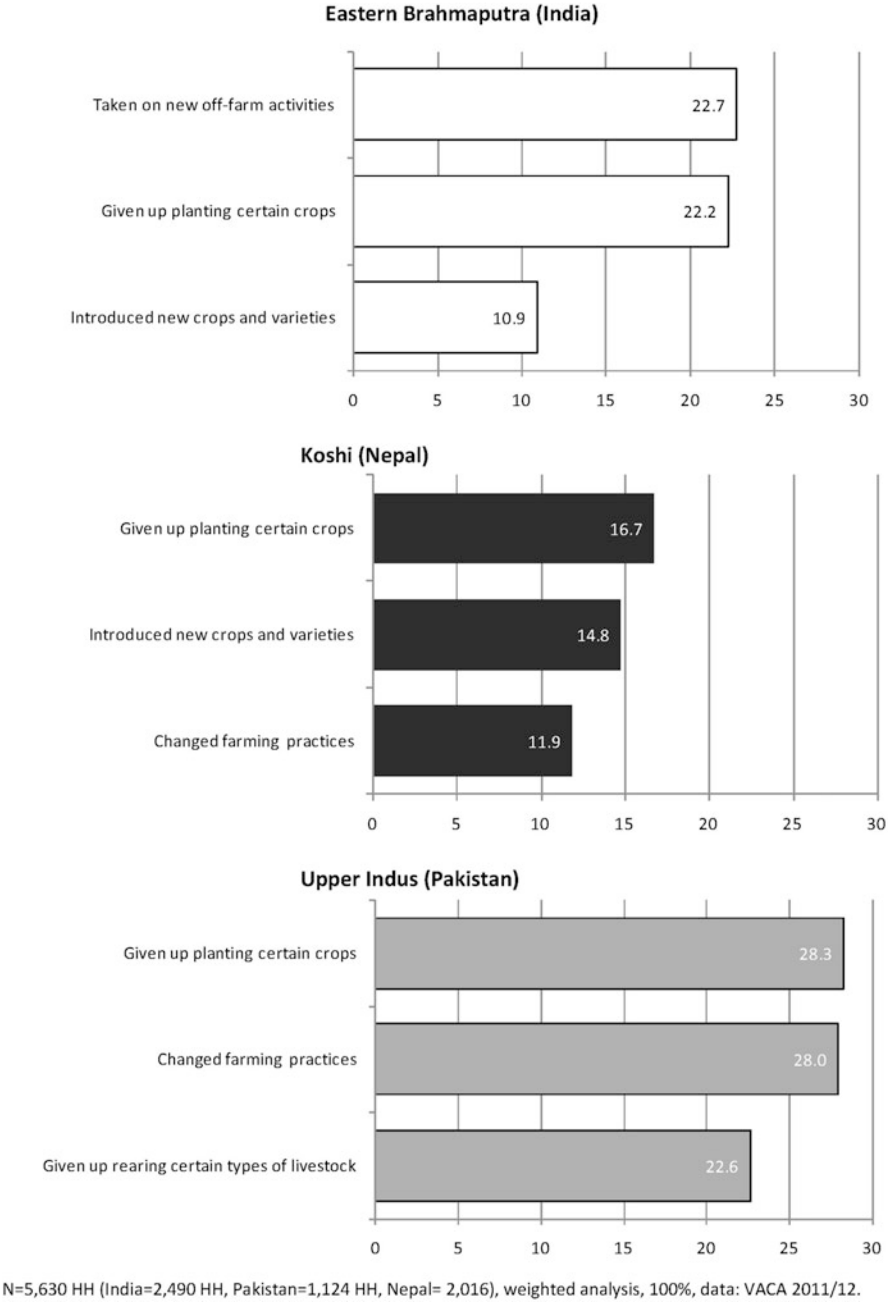


Fig. 6 The three most common coping strategies to deal with environmental changes over the last 10 years by sub-basin (in % of HH)

and overall water availability in a region where people are greatly dependent on agriculture, both for subsistence and for growing cash crops, result in uncertainty regarding the timing of crop production which can lead to lower productivity and even crop failure (Bartlett et al. 2010; Gentle and Maraseni 2012). Furthermore, erratic precipitation patterns affect rangelands and forests and thus have impacts on the grazing of livestock and the availability of non-timber forest products (Gentle and Maraseni 2012).

The main short-term coping strategies reported by the households of the three sub-basins were borrowing money and reduced consumption of basic goods. According to Corbett (1988), these are primary coping strategies applied to deal with disasters, which are, when exhausted, followed by the disposal of productive assets (e.g., sale of livestock or agricultural land). Taking loans places additional stress on families, promotes exploitation, and is pushing poor households toward indebtedness and a vicious cycle of poverty (Gentle and Maraseni 2012). This is actually reflected in the relatively high number of households that have reported indebtedness as one of the main socioeconomic shocks. Furthermore, these short-term coping strategies are not sustainable in view of predicted climate change associated with increasing temperatures and an increase in the frequency and magnitude of extreme events (Nogues-Bravo et al. 2007; IPCC 2012) as they deplete the asset base and thus render households even more vulnerable to recurring shocks.

Although a vast majority of the households in the three sub-basins have perceived climatic and environmental changes during the last 10 years, the percentage of households that have applied medium-term coping measures was relatively low. These results are in line with other findings of recent studies from the region that show that people often do not react to perceived changes because they lack resources, information, and/or government support (Gentle and Maraseni 2012; Gambhir and Kumar 2013; Colom and Pradhan 2013; Zaheer and Colom 2013). The most important medium-term coping strategies employed by households included giving up certain crops, changing farming practices (e.g., earlier sowing or harvesting), and introducing new crop varieties. While the first two strategies are reactive and may lead to decreased productivity and thus increase vulnerability, the latter could be regarded as a proactive adaptation measure, given that farmers have anticipated changes and therefore adjusted their farming practices accordingly. A recent qualitative study by Macchi et al. (forthcoming) in Nepal and Northwest India provides an example of mountain farmers who took advantage of new opportunities offered by increasing temperatures: the farmers grew millet and certain fruits at altitudes where they had not thrived before or cultivated more than one crop cycle per year.

Given the rather low percentage of households that addressed change in a proactive manner and the fact that most of the observed response mechanisms to change were natural resource based and therefore highly susceptible to changing climatic conditions, awareness rising and capacity building at all levels of society (from government institutions to households), improved communication of tailor-made information, and a synergy between adaptation and development interventions are essential. This, again, requires assessments of the location-specific situation and the specific needs of all stakeholders.

Conclusion

The people of Hindu Kush Himalayas are confronted with rapid socioeconomic, demographic, and environmental changes. To explore their vulnerability and adaptive capacity, the International Centre for Integrated Mountain Development has developed a survey instrument (VACA questionnaires) and had collected data of almost 6,100 households of three of its regional member countries as part of the *Himalayan Climate Change Adaptation Programme (HICAP)*. This chapter presented the methodology of the VACA study, i.e., the operationalization of livelihood vulnerability in the VACA questionnaires and the research design of the VACA survey. At the end, the usefulness of the assessment was illustrated by presenting preliminary findings.

At the moment, the project is ongoing and several tasks are performed. One of them is the development of a multidimensional livelihood vulnerability index (MLVI) for the HKH region, which allows an effective way of describing and comparing of livelihood vulnerability and its trigger across the study sites. Besides, the data provide a rich basis for the quantitative analysis of various research questions, such as the causes and effects of vulnerability and adaptive capacity. In this regard, it seems fruitful to have a closer look into short-term and medium-term exposure and the respective coping strategies: who is doing what and with what kind of results?

The survey data will provide a baseline for further in-depth studies, both qualitative and quantitative, and interventions that are planned within HICAP. Based on VACA, it will be possible to identify relations and interdependencies on an aggregated level, while in-depth studies will help to explore the underlying mechanisms. Given the lack of household-level data on vulnerability and adaptive capacity in the studied river basins, VACA can provide significant insights for the adaptation planning at the district level. In addition, the survey data will be linked up with available metrological and environmental data as well as information on hazards in the respective sub-basins. In that sense, VACA is one of several pillars within the mixed-method approach chosen for HICAP.

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Climate Change and Displacement in Bangladesh: Issues and Challenges

Nour Mohammad

Contents

Abstract

The purpose of this chapter is to explain and come to an understanding of the causes of forced migration and climate displacement due to the climate change in the present era of globalization. Environmental crisis along with the increasing impacts of climate change in Bangladesh has become an important cause of cross-border migration to South Asian countries. This chapter attempts to focus on migration and climate displacement in Bangladesh. The research is based upon theoretical sources and empirical data. The consequences of such movement of population in South Asian context will generate a range of destabilizing sociopolitical, economic, and climate change impacts in the future. Bangladesh is commonly recognized as one of the most climate-vulnerable countries on earth and is set to become even more so as a result of climate change. This chapter underlines that climate displacement is not just a phenomenon to be

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addressed at some point in the future; it is a crisis that is unfolding across Bangladesh now. Sea-level rise and tropical cyclones in coastal areas as well as flooding and riverbank erosion in mainland areas, combined with the socio-economic situation of the country, are already resulting in the loss of homes, land and property which are common phenomenon in Bangladesh. Among the many causes of vulnerability of people, cross-border migration due to climate change might increase the susceptibility of people to climate change in South Asian countries. This chapter examines the details of legal framework of current and future causes of climate displacement in Bangladesh. It further analyzes existing government policies and programs intended to provide solutions to climate displacement and relief to climate displaced persons and emphasizes that rights-based solutions must be utilized as the basis for solving this crisis.

Keywords

Climate change • Displacement • Environmental migrants • Vulnerability • Policy • Bangladesh

Introduction

Climate change is one of the most serious threats in the present world. It will affect all of us but will have a disproportionate impact on millions of poor rural people of developing countries. It puts more people at risk of hunger and makes it more difficult to reduce the proportion of people living in extreme poverty. For development work to be effective, we must help poor rural people cope with and mitigate the impact of climate change. The concept of climate and displacement is not a new phenomenon and can be traced back to earlier deliberations on environmental displacement, which were particularly prominent during the 1990s. Climate change has emerged as the greatest threat faced by human beings in the modern world (Clime Asia 2009). The adverse effects of climate change destabilize the human displacement, economic development, human security, and people's fundamental right (UNDP 2007). Climate change, environmental degradation, and migration are among the key topics that dominate the international and national political arena today. Environmental migration is a reality that can no longer be overlooked. Millions of people have already been displaced as a result of climate change and climate-related natural disasters like *Alia* and *Sidr* in Bangladesh. The affected people are also moving from one place to another because of environmental disaster and not able to continue their livelihood anymore. The Red Cross research shows that more people are now displaced by environmental disasters than by war. The United Nations University predicts that 50 million people globally will be displaced by environmental crises by the year 2010. According to other experts in the relevant field, there could be as many as 200 million displaced worldwide by 2050. Although these numbers are expertly researched estimates, even the predictions on the lowest end of the scale are immense.

The concept of migration is not a new one; it has been developed for thousands of years ago. This phenomenon is new because there are more and more people that are forced to flee their homes due to environmental factors and natural disaster related to climate change. The complex interdependence between these phenomenon and the potential consequences of the failure to tackle them in time are beginning to attract increasing public and scientific attention. The manifested political commitments to the pursuit of sustainable development, environmental protection, and the respect, protection, and fulfillment of human rights and even more so to their interlinkages are often limited by narrow geopolitical interests when action becomes necessary. Bangladesh is widely recognized to be one of the most climate-vulnerable countries in the world. It is found that in every year, natural disaster frequently happens, which causes loss of life and damage to infrastructure and economic assets and adversely impacts on lives and livelihoods, especially of poor people (BCCSAP 2008). Climate change is considered to be a critical global challenge and recent events have demonstrated the world's growing vulnerability to climate change. The impacts of climate change range from affecting agriculture to further endangering food security, to rising sea levels and the accelerated erosion of coastal zones, and to increasing intensity of natural disasters, species extinction, and the spread of vector-borne diseases (United Nations Permanent Forum on Indigenous Issues 2007). Bangladesh has developed some facility for dealing with the impacts of climate change at the national level and policy response options has been mobilized that deal with vulnerability reduction to environmental variability and most recently to climate change in particular (Saleemul Haq. Ayers 2007).

Climate Change and Bangladesh

Bangladesh is one of the largest deltas in the world which is highly vulnerable to natural disasters because of its geographical location, flat and low-lying landscape, population density, poverty, illiteracy, lack of institutional system, etc. In other words, the physical, social, as well as economic conditions of Bangladesh are very typical to any of the most vulnerable countries to natural disasters in the world. The total land area is 147,570 km^2 and consists mostly of floodplains (almost 80 %) leaving major part of the country (with the exception of the northwestern highlands) prone to flooding during the rainy season. Moreover, the adverse affects of climate change especially high temperature, sea-level rise, cyclones and storm surges, salinity intrusion, heavy monsoon downpours, etc. has aggravated the overall economic development scenario of the country to a great extent (Anne Katrien 2012). Climate change is an important issue in the effort for global peace. The global temperatures and sea levels are changing day by day. The whole world is apprehended about the unnatural changes occurring in global climate. The issue of global climate change that we are facing is more pressing than ever (BCCSAP 2009). In Bangladesh the climate change is affecting the human life and economical development and causing displacement of human being. Due to global warming, the country has experienced unusual changes in seasons and faces unexpected rains, dry spells, temperatures, and other symptoms of changes in global weather patterns.

Bangladesh's vulnerability to climate change lies mainly in its density of population and that a large part of its area consists of low-lying coastal areas and expansive floodplains. Now Bangladesh has a population of 163 million people (Bangladesh Demographic Report 2013). While the country's population has been increasing, on the one hand, its forests are being depleted on the other (Jahangir Alam 2009). An increasing world population and harmful industrialization by the developed countries are the main causes of climate change. The severity of storms, droughts, rainfall, floods, and other natural disasters has been increasing in developing countries like Bangladesh in particular, due to climate change. Global warming threatens our agriculture also, which is the backbone of a country. Every year, natural disasters occur like *Sidr* and *Alia* causing havoc effects on Bangladesh agriculture, touching every corner of the country. Due to lack of resources and other causes, Bangladesh does not have the capacity to ensure that appropriate measures are taken to mitigate the damage (Ahamed 2008).

The coastal areas of Bangladesh and the coastal people are mostly affected by the climate change and they are losing ponds, lakes, dams, and forestry due to natural disaster. National and regional varieties of fish are being lost due to such climate disaster. Specialists have consensus that 54 varieties of fish in Bangladesh have already been lost due to climate change and natural disaster, and forest and animals are also being lost. Most of the people in Bangladesh are living in rural areas and lead a very poor life. According to the Water Development Board, there is a total of 11,000 km of embankment that the Water Development Board developed, of which around 250 km were damaged by water surges during cyclones *Sidr* and *Alia*. The existing embankment at Moheshkhali under Cox's Bazar District requires a 4.5 m height increase to protect against storm surges and sea-level rises due to the effects of climate change. Any future embankments should be designed to be 2–4 m higher than the existing ones. Due to climate change, the weather in Bangladesh has changed. Water levels have fallen, temperatures have risen, and the incidence of floods, dry spells, and cyclones have all increased, affecting both people's lifestyle and the crops. At least 30 rivers, including the Padma, the Gomti, and the Teesta, have dried up. And most of the other rivers in Bangladesh are being lost because they are being filled with soil. Parts of northern Bangladesh are becoming desert. Geological and biological changes in the area are threatening normal life (Shamsudoha and Chy 2009). Bangladesh needs technological and economic support to survive the effects of a changing climate. Just as important is the proper handling of any foreign funds Bangladesh may get, since we know that corruption is another large barrier to our prosperity.

Causes of Climate Change and Displacement: The Present Scenario

The main causes of environmental deterioration or devastation forcing people to move from their natural habitat are many and varied. The primary causes of climate displacement in Bangladesh tidal height increases in the coastal areas and riverbank erosion in the mainland areas. The secondary causes of displacement are tropical cyclones and storm surges in the coastal regions and river flooding in the mainland. The main scenario sites of displacement have been in the coastal areas and in the river delta regions in the mainland. Bangladesh has 64 districts of them 24 coastal and mainland districts have already producing climate displaced peoples (Climate displacement Report 2012).

Impacts related to climate change could be divided into two distinct drivers of migration:

(a) Long-term climate processes (for instance, sea-level rise, salinization of agricultural land, desertification, soil erosion, water scarcity)
(b) Short-term extreme climate events and extreme weather events (for instance, flooding, hurricanes, storms)

According to International Organization for Migration (IOM), climate change is likely to affect the movement of people in at least four ways: (i) the intensification of natural disasters like both sudden and slow onset leading to increased displacement and migration; (ii) the adverse consequences of increased warming, climate variability and of other effects of climate change for livelihoods, public health, food security, and water availability; (iii) rising sea levels that make coastal areas tumble down; and (iv) competition over scarce natural resources potentially leading to growing tensions and even conflict and, in turn, displacement. The consequences of climate change (including its effects on migration) will be most severe for the developing world like Bangladesh. Particular areas including the Asian mega deltas have been identified as "hotspots" where greater revelation and sensitivity to climate change combine with limited adaptive capacity to suggest that impacts will be most significant (IOM 2008).

The proposed working definition of migrant by the International Organization for Migration (IOM) is that environmentally induced migration or environmental migrants to encompass people who move as a result of natural or human-made disasters as well as those who migrate because of deteriorating environmental conditions. According to this definition, environmental migrants are those "Environmental migrants are persons or groups of persons who, for reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are obliged to have to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their territory or abroad."

This definition is inclusive of all persons who have an environmental factor as the major cause of migration and acknowledges that environmentally induced migration can be internal as well as international and a short- or long-term phenomenon, due to sudden or gradual environmental change, without ignoring other intervening political, economic, and social factors.

One of the most basic issues in climate change and environmentally induced migration is that it is an international issue or process, but not a regional or local issue. The international community has the responsibility to provide adequate measures for prevention, adaptation policy, and mitigation community in order for the mostly affected countries to reduce their vulnerability to the impacts of environmental disasters and manage the development of environmental processes. The local and national authorities have no power to engage in proactive intervention to reduce the crisis of climate change. Environmentally induced migration is rarely mono-causal. The cause-consequence relations are increasingly complex and multifactorial (Myers and Kent 1995). A growing number of people flee because of multiple causes of injustice, exclusion, environmental degradation, competition for scarce resources, and economic hardship caused by dysfunctional states. Some people leave voluntarily, some flee because there is no other choice, and some may make the decision to move before they have no other choice but to flee. The different degrees of force and the complex set of influencing factors blurs the traditional concepts of migration and displacement, creating confusion among the academia and the international community about whether to talk about migration or displacement in the case of people fleeing disasters and environmental degradation (Tina 2008).

There is a scientific perception that the effects of the climate change are frustrating; many of the natural environmental hazards already faced by Bangladesh in every year (McAdam and Saul 2010) are sudden-onset events including floods, cyclones, storm surges, waterlogging, salinity intrusion, and riverbank erosion and slow-onset events such as coastal erosion, sea-level rise, saltwater intrusion, etc.

Bangladesh's vulnerability to natural hazards leads to climate displacement – the forced displacement of individuals and communities from their homes and lands. This is as a result of both "sudden-onset events" such as floods, cyclones, and riverbank erosion as well as "slow-onset processes" such as coastal erosion, seal-level rise, saltwater intrusion, changing rainfall pattern and drought, etc. (Siddiqui 2011).

Alarmist prediction is that some 30 million people will be displaced from Bangladesh by 2050 as a result of climate change (McAdam and Saul 2010). It is projected that six million people have already been displaced by the effects of climate hazards in Bangladesh.

However, human displacement and migration is a multi-causal phenomenon even in cases where climate change is a predominant driver of migration; it is usually compounded by social, economic, political, and other factors. Resource, social network, cultural ability to cope with change, individual's attitude, position in family decision making, and gender contribute to decision to migrate or not (Matthew 2010).

It is estimated that 60,000 deaths from climate-related natural disasters occur every year (UN News Service 2007) and that 30 million people worldwide are being displaced because of serious degradation of environmental conditions, natural disasters, and depletion of natural resources. This figure is expected to soar by the middle of this century. While there are no authoritative global figures on the number of people who will move for environmental reasons in the future, the Stern Review provides an estimate of 150–200 million becoming permanently displaced due to the effects of climate change by the year 2050 (Stern 2006).

However, the international community is largely ignoring the issue that may potentially become one of the greatest global demographic and humanitarian challenges for the twenty-first century (Myers and Kent 1995).

Climate Displacement in Bangladesh: Future Situation

Bangladesh has total 64 districts, of which 24 districts are coastal and mainland from which people are displaced. Bangladesh having 160 million people is highly vulnerable to climate change and displacement due to sea-level rise (Rabbani 2009). Twenty-eight percent of the population of Bangladesh lives in the coastal regions of the country (Rafiqul Islam 2007).

Climate change is one of the greatest challenges for the world today. The effects of climate change will aggravate many of the natural hazards faced by Bangladesh in every year, including all of the natural hazards currently leading to climate displacement: flooding, tropical cyclones, storm surges, salinity intrusion, and riverbank and coastal erosion and SLR. The Intergovernmental Penal of Climate Change (IPCC) has provided that climate change and global warming are likely to lead to an increase of rainfall, rise in the frequency of flash floods and large-area floods, earlier melting of snowpacks and melting of glaciers, frequent and intense droughts, intense tropical cyclones, rising sea levels, frequent and intense storm surges, and intense inland rainfall and stronger winds (IPCC 2007). Sea-level rise from climate change is anticipated to worsen many of these processes and to subsume up to 13 % of Bangladesh's coastal land by 2080 (Pender 2008).

Heavier and more erratic rainfall in the Ganges-Brahmaputra-Meghna system is likely to lead to further riverbank erosion resulting in mass displacement in the mainland areas of Bangladesh. Besides, erratic rainfall is also likely to lead to overtopping and breaching of embankments resulting in widespread flooding in both urban and rural areas. In addition, it is likely to lead to increasing droughts, especially in the drier northern and western regions of Bangladesh which record significantly less rainfall causing the destruction of crop yields and severe disruption to livelihoods (IPCC Third Assessment Report 2001). Erratic rainfall is likely to lead to increasingly frequent and severe landslides in the hill regions of Bangladesh triggering human exodus. As the Himalayan glaciers continue to melt, it is likely that there will be higher river flows in the warmer months of the year, followed by lower river flows and increased saline intrusion after the glaciers have shrunk or disappeared (Displacement Solution Report in Bangladesh 2012).

The difficulty inherent in predicting the future impact of climate change on displacement in Bangladesh means that any attempt to quantify the exact number of climate displaces should be treated with some caution. However, as all of the key current drivers of displacement are expected to increase in both frequency and intensity due to climate change, it is highly likely that the number of climate displaced due to existing factors will continue to increase in the future in Bangladesh. In addition, the number of climate displaced is likely to rise even higher due to secondary and as yet unforeseen effects of climate change (Haque 1996).

Existing Potential Policies and Institutional Frameworks in Bangladesh

Bangladesh, being one of the most vulnerable countries, has adopted a number of policies and institutional frameworks over the recent years. These measures have been undertaken to combat frequent natural disasters and the adverse effects of climate change.

Policies and Institutional Framework on Environment in National Level

The Government of Bangladesh has adopted a number of national policy and framework for the protection of environment and natural disaster. National Environmental Policy 1992 and the Coastal Zone Policy 2005 deal with the adverse effects of disasters and environmental problems (Roy 2012). But there is no clear indication about the problems of population displacement. In terms of guiding strategies on the environment, among the key documents is the National Environmental Management Action Plan 1996, the more recent National Capacity Self-Assessment (NCSA) for Global Environmental Management 2007, and the sector-specific environmental policies such as the National Water Policy 1999 and the Guidelines for Participatory Water Management. All of these documents are understandably focused on meeting Bangladesh's current environmental challenges and make few specific references to the migration effects of environmental change and degradation (although the NSCA refers to the problems of displacement by river-bank erosion, rural-urban migration, and the potential for out-migration from coastal zones). In contrast, policies on disaster management such as the Draft National Plan for Disaster Management 2008 do make reference to displacement and specific vulnerabilities related to migration, such as problems faced by families who are left behind when men out-migrate following an event (Walsham et al. 2012).

The institutional framework of Bangladesh consists of different disaster management committees at different levels comprising government, nongovernment, voluntary, and other relevant stakeholders. The National Disaster Management Council (NDMC), headed by the Prime Minister, is established to provide guidance towards disaster risk reduction and emergency response management in Bangladesh and is the highest-level forum for the formulation and review of disaster management policies. The Inter-Ministerial Disaster Management Coordination Committee is responsible for implementing disaster management policies and the decisions of the NDMC and is assisted by the National Disaster Management Advisory Committee (Roy 2011). The Ministry of Food and Disaster Management is the focal ministry for disaster management in Bangladesh. Its Disaster Management Bureau (DMB) is mainly responsible for coordinating national disaster management interventions across all agencies. In 2000 the government published "Standing Orders on Disaster" which provides a detailed institutional framework for disaster risk reduction and emergency management and defines the roles and responsibilities of different agencies and committees (BCCSAP 2008).

Existing Policies and Institutional Mechanisms on Climate Change in Bangladesh

The Government of Bangladesh has taken many steps to address adaptation to climate change including the establishment of a 45-million-dollar Climate Change Fund, the development of the Bangladesh National Adaptation Programme of Action in 2005 (NAPA), and the Bangladesh Climate Change Strategy and Action Plan 2009 (Fatima and Anita 2010).

The National Adaptation Programme of Action in 2005 (NAPA)

The Government of Bangladesh has adopted the National Adaptation Programme of Action in 2005 (NAPA) prepared by the Ministry of Environment and Forests. The NAPA aimed to accumulate the understanding of the current state of affairs from discussions with appropriate stakeholders from four subnational workshops and one national workshop (MOEF 2005). The NAPA was prepared keeping in mind the sustainable development goals and objectives of Bangladesh where the importance of addressing environmental issues and natural resource management with the participation of stakeholder in bargaining over resource use, allocation, and distribution was recognized (BCAS 2008). The NAPA recognizes that Bangladesh will be one of the most adversely affected countries due to climate change especially because of Bangladesh's "low economic strength, inadequate infrastructure, low level of social development, lack of institutional capacity and a higher dependency on the natural resource base."

The NAPA suggested adopting the following measures for Bangladesh to adverse effect of climate change including variability and extreme events based on coping mechanisms and practices. The suggested future adaptations are (MOEF 2005):

(i) Reduction of climate change hazards through coastal afforestation with community participation
(ii) Providing drinking water to coastal communities to combat enhanced salinity due to sea-level rise
(iii) Capacity building for integrating climate change in planning, designing of infrastructure, conflict management, and land-water zoning for water management institutions
(iv) Climate change and adaptation information dissemination to vulnerable community for emergency preparedness measures and awareness rising on enhanced climatic disasters
(v) Construction of flood shelter and information and assistance center to cope with enhanced recurrent floods in major floodplains

(vi) Mainstreaming adaptation to climate change into policies and programs in different sectors (focusing on disaster management, water, agriculture, health, and industry)
(vii) Inclusion of climate change issues in curriculum at secondary and tertiary educational institution
(viii) Enhancing resilience of urban infrastructure and industries to impacts of climate change
(ix) Development of eco-specific adaptive knowledge (including indigenous knowledge) on adaptation to climate variability to enhance adaptive capacity for future climate change
(x) Promotion of research on drought-, flood-, and saline-tolerant varieties of crops to facilitate adaptation in the future
(xi) Promoting adaptation to coastal crop agriculture to combat increased salinity
(xii) Adaptation to agriculture systems in areas prone to enhanced flash flooding in North East and Central Region
(xiii) Adaptation to fisheries in areas prone to enhanced flooding in North East and Central Region through adaptive and diversified fish culture practices
(xiv) Promoting adaptation to coastal fisheries through culture of salt-tolerant fish special in coastal areas of Bangladesh
(xv) Exploring options for insurance and other emergency preparedness measures to cope with enhanced climatic disasters

In 2005 NAPA identified some adverse impacts of climate change, many of which link with climate displacement such as scarcity of freshwater due to less rain and higher evapotranspiration in dry seasons, drainages congestion due to higher water level in the confluence of the rise of sea level, riverbank erosion, frequent flood and widespread drought, and salinity in the surface, ground, and soil in the coastal zone due to migration; however, these links were not expressed in concrete terms. The document also stated that a potential long-term consequence of the "adaptation to agriculture systems in areas prone to enhanced flash flooding" project would be that "people might get a means to continue with farming, instead of migrating to cities after the flood."

Bangladesh NAPA has moved from the urgent needs to wider adaptation requirement to address medium- and long-term climate issues. It gave emphasis on four basic national security issues of Bangladesh, i.e., (a) food security, (b) energy security, (c) water security, and (d) livelihood security (including right to health) and respect for local community on resource management (Haque 2011).

The Climate Change Strategy and Action Plan in 2009 (BCCSAP)

Bangladesh Climate Change Strategy and Action Plan is the most recent document formulated by the government aiming to address the adaptation and mitigation to build the capacity and reliance of the country to climate change for a period of decade 2009–2018. The plan was prepared in 2009 focusing on a 10-year program to encounter the potential challenges and variation condition (BCCSAP 2009).

BCCSAP identifies all the climate-induced hazards, including flood, drought, salinity intrusion, cyclone and storm surge variations in temperature and rainfall, etc., and their associated impacts on different sectors. BCCSAP identifies a set of activities/measures under the following six major themes:

(i) Food security, social protection, and health
(ii) Comprehensive disaster management
(iii) Infrastructure
(iv) Research and knowledge management
(v) Mitigation and low carbon development
(vi) Capacity building and institutional strengthening

The BCCSAP recognizes that "Bangladesh is one of the most climate vulnerable countries on earth and will become even more so as a result of climate change" (IPCC Third Assessment Report 2001) and highlights the many risks of the effects of climate change that have led to displacement, including floods, tropical cyclones, storm surges, and droughts.

It states that increased riverbank erosion and saline water intrusion in coastal areas "are likely to displace hundreds of thousands of people" and that if sea-level rise is higher than currently expected and coastal polders are not strengthened and/or new ones built, "six to eight million people could be displaced by 2050 and would have to be resettled."

The BCCSAP provides that "it is now evident that population in many parts of the country will be so adversely affected [by climate change] that they will have to move out. . .The process of migration of climate change-affected people, both inside and outside the country, need[s] to be monitored closely. . .and adequate institutional support should be provided for their proper resettlement."

In addition to these two mechanisms, there are some existing traditional climate change-related fund mechanisms in Bangladesh to address the issue of climate change. Bangladesh Climate Change Trust Fund (BCCTF) based on revenue from the national budget, within a legal mandate by the Climate Change Trust Act passed in Parliament in 2010. At the same time, an alternate Bangladesh Climate Change Resilient Fund (BCCRF), which was formerly known as the Multi-donor Trust Fund (MDTF), was created to pool funds from the country's development partners.

Bangladesh Climate Change Trust Fund (BCCTF)

The Bangladesh Climate Change Trust Fund is a "block budgetary allocation" of US$ 100 million each year for 3 years (2009–2012). The Climate Change Act provides that an amount equivalent to 66 % of the total fund is being spent for the implementation of BCCSAP while 34 % will be maintained as a "fixed deposit" for emergencies. The interest accrued on the 34 % fixed deposit will also be spent on project implementation. Funds from the BCCTF can be used to finance public sector and 10 % for nongovernment projects, and it is not mandatory to spend the total grant within a given financial year (Munjurul et al. 2006).

Bangladesh Climate Change Resilience Fund (BCCRF)

Bangladesh Climate Resilience Fund (BCRF) has also been created by the government for supporting actions to address climate change. Mainly international development partners of Bangladesh are contributing to create this fund. In April 2008, a UK-Bangladesh Climate Change Conference was held in Dhaka. The development partners expressed their view for the urgency of establishing a "financial mechanism" to assist Bangladesh in combating the impacts of climate change. Subsequently, the London Climate Change Conference was organized jointly by Bangladesh and the UK in September 2008.

However, finally in May 2010, DPs in Bangladesh Development Forum (BDF) agreed the establishment of BCCRF which would be managed by the Government of Bangladesh (GoB). World Bank is providing "fiduciary" support to the BCCRF with an objective of handing it over to the GoB in the next 3 years. By this time the BCCRF has received an approximate amount of 200 million USD from different DPs including UK, EU, Denmark, Sweden, and Australia. An amount of 90 % of the total amount would be spent by different ministries while the rest 10 % would be managed by PKSF to support initiatives taken by NGOs and Bilateral Development Partners (Hoque 2007).

Sectoral Adaptation Policies

Bangladesh has developed a good number of sectoral adaptation policies since 1990. Considering the fact that Bangladesh is highly susceptible to climate change, only one sectoral policy on the coastal zone has considered climate change (BCAS 2010). The National Water Policy (NWP) was formulated in 1999, considered firstly short-, medium-, and long-term perspectives for water resources in Bangladesh. The NWP was followed by the National Water Management Plan (NWMP) in 2001. Though there is a huge effect of climate change on water resources in Bangladesh, the NWP does not mention the climate change issue at all. However, the NWMP identifies climate change as one of the future elements affecting supply and demand of water. The National Environmental Management Action Plan (NEMAP), which was published in 1995, does not illuminate climate change. Similar to NEMAP, the National Land Use Policy (NLUP) and the National Forest Policy (NFoP) do not make direct reference to climate change. Climate change was not also addressed in the Poverty Reduction Strategy (PRS) papers until recently. The present PRS recognizes the threat of climate change and its adverse impacts on the development process. It understands the need for integration/mainstreaming. Integration/mainstreaming of adaptation measures into other policy areas and the implementation of the adaptation projects were identified in the NAPA (BCAS 2010).

Institutional Mechanisms

There are many departments in Bangladesh working for institutional mechanisms for climate change. The Ministry of Environment and Forests (MOEF) is mainly responsible for policy formulation on climate change and its adaptation while the Climate Change Unit (CCU) and Department of Environment (DOE) implement projects and programs under NAPA and BCCSAP at the community level. The National Steering Committee on Climate Change (NSCCC), chaired by the Minister of MOEF, is composed by secretaries of all climate-affected ministries, divisions, and representatives of civil society and business community. The National Environment Committee under the ministry is expected to mainstream climate change into national development planning. Climate Change Focal Points (CCFP) in various ministries are expected to provide collaboration. Five technical working groups have been constituted for adaptation, mitigation, technology transfer, financing, and public awareness (Country Summary Report 2010).

Climate Change and Internal Displacement: International Legal Framework

Bangladesh ranks as the country most at risk of natural disaster. The displacement occurs in the immediate, sudden onset such as flood, cyclones, and riverbank erosion, etc.; the people move from one place to another place and seek to return to their homes as soon as they can, but sometimes it is quite impossible to return to their homes when the areas are repeatedly inundated. Displacements due to sudden onset are predominantly localized in Bangladesh. The people living in the vulnerable areas are very poor and lack resources; they do not move to a long-distance place and do not have any support from the networks of other countries. They remain in their home country and qualify as an internal displacement.

Guiding Principles in Internal Displacement (1998)

The guiding principle on internal displacement is one of the promising initiatives at the international level to promote and provide protection and assistance for internally displaced person (IDPs). These principles fill a major gap in the international protection system for the rights of IDPs and the obligation of governments and insurgent forces in all phases of displacement. They offer protection before internal displacement occurs (i.e., protection against arbitrary displacement), during situations of displacement, and in postconflict return and reintegration.

The United Nations officially first dealt with internally displaced persons in 1972, but did not define who exactly would be considered to be internally displaced. ECOSOC res. 1705 (LIII), 27 Jul. 1972. *Para.* 1 of resolution 1705 provides that "The Economic and Social Council urges Governments, The United Nations High Commissioner for Refugees, specialized agencies and other organizations associated with the United Nations and nongovernmental organizations concerned, to provide the assistance required for the voluntary repatriation, rehabilitation and resettlement of the refugees returning from abroad, as well as persons displaced within the country."

Francis Deng, nominated as Special Representative of Secretary-General on the human rights issues related to internally displaced persons by Commission on Human Rights in 1992, further refined the existing definitions. In 1998, he submitted a set of "Guiding Principles on Internal Displacement" to the Human Rights Commission.

The needs of the IDPs stem from twofold danger (Geissler 1999):

(a) Whenever persons are forced to leave their homes or places of habitual residence, multiple human rights violations, such as acts of violence, armed attack, torture, disappearances, or rape, are committed on them.
(b) There is no clearly defined institutional protection for IDPs and have only little coordinated ad hoc responses.

Several initiatives have been taken to address the plight of internally displaced persons more efficiently. In the quest for a more effective response, the international community has concentrated its efforts along two main lines, that of identifying an appropriate normative framework and that of developing effective institutional arrangements. The Representative of the Secretary-General on internally displaced persons, Mr. Francis Deng, has been catalytic to these initiatives and, more generally, to stimulating a better understanding of the numerous complex issues associated with internal displacement.

A number of international bodies, guidelines, and standards also exist which specifically protect the rights of displaced persons. These include the Guiding Principles on Internal Displacement, the *Pinheiro Principles*, the United Nations Inter-Agency Standing Committee's Guidelines on Human Rights and Natural Disasters, the Human Rights Council Resolution 7/23 and 10/4 on Human Rights and Climate Change, the 1951 Geneva Convention, the Code of Conduct for the International Federation of the Red Cross and Red Crescent Societies and NGOs in Disaster Response Programmes, the Responsibility to Protect of the International Commission on Intervention and State Sovereignty, and the Humanitarian Charter of the Sphere Project.

The United Nations Principles on Housing and Property Restitution for Refugees and Displaced Persons (the Pinheiro Principles) (UN Sub-Commission 2005). There are 23 principles recognizing the right to be protected from displacement, right to housing and property restitution, right to nondiscrimination, right to equality between men and women, right to privacy and respect for the home, right to peaceful enjoyment of possessions, right to voluntary return and safety, right to freedom of movement, etc.

The United Nations Inter-Agency Standing Committee's Guidelines on Human Rights and Natural Disasters (IASC 2006) ensures that displaced persons or those otherwise affected by natural disasters do not lose the rights of the population at large, and at the same time, they have particular needs which call for greater protection and assistance measures. It also states that protection is not only limited to securing survival and physical security but also encompasses all aspects of civil, political, economic, social, and cultural rights as afforded by international standards.

The Human Rights Council Resolution on 28 March 2008 adopted its first resolution 7/23 (HRCU 2008) and on 25 March 2009 adopted another resolution *10/4 on Human Rights and Climate Change*, recognize the relationship between human rights and climate change, and also climate change-induced displacement. It also recognizes that climate change is a global problem and that it requires global solution. The Human Rights Council has taken the decision to hold panel discussions on the relationship between climate change and human rights in order to contribute to the realization of the goals set out in the Bali Action Plan.

The 1951 Refugee Convention while not providing protection for persons fleeing environmentally harm and natural disaster could be useful in narrow circumstances whereby victims are entitled to protection under the principle of *non-refoulement*. This would prevent a government's return of a person from their country regardless of legal status, where the person's life or integrity are at risk or where return would subject the person to cruel, unusual, or degrading treatment.

The Code of Conduct for the International Federation of the Red Cross and Red Crescent Societies and NGOs in Disaster Response Programme affirms that the humanitarian imperative comes first and without any discrimination and that disaster-affected victims will be recognized and treated as dignified humans.

The doctrine of responsibility to protect was first established in 2001 by a group of prominent human rights leader comprising the Report of the International Commission on Intervention and State Sovereignty on the Responsibility to Protect which aims to develop "global political consensus about how and when the international community should respond to emerging crises involving the potential for large-scale loss of life and other widespread crimes against humanity."

The said doctrine reaffirms that the primary responsibility for the protection of its displaced people, but that in situations where this is not possible or not being done, the international community will intervene which includes scenarios of overwhelming natural or environmental catastrophes.

The Humanitarian Charter and Minimum Standards of the Sphere Project is structured around the three core principles of the right to life with dignity, the right to protection and security, and the right to receive humanitarian assistance. The minimum standards ensure that affected persons have access to at least the minimum requirements of water, sanitation, food, nutrition, shelter, and healthcare in order to satisfy their basic right to life with dignity. Although these guidelines and instruments are not legally binding, they provide a *soft law* approach to dealing with the issue of displaced persons. It should be mention here that most of these instruments only cover displacement caused by natural disasters and do not take into account displacement caused by environmental degradation such as desertification or movement caused indirectly by climate change. It is predicted that the majority of climate change-induced displacement be caused indirectly, and therefore, there is an urgent need to formulate a framework for the protection of their rights (Fitma et al. 2010).

Conclusion

Climate change poses a dreadful challenge for all countries, but its major impact will be on developing countries like Bangladesh. Climate displacement in Bangladesh, which is increasing day by day due to climate change, increases the frequency and intensity of the natural hazards that are already leading to displacement in Bangladesh. It is very essential to take effective and appropriate arrangement to make a durable solution to this growing issue. However, migration policy should be better integrated into the national development agendas as well as development cooperation. Development cooperation can help vulnerable communities living in absolute poverty to mitigate the impacts of environmental degradation and climate change and to reduce their vulnerability to the effects of such phenomena. Development strategies must in the future also pay more heed to the sustainability of development plans in the light of foreseeable climate impacts at local level. For example, the agricultural development of a region likely to be strongly affected by drought in the future should be reevaluated (Committee on migration, refugee and population 2008).

Climate change and climate change-related effects have a horrific impact not only on the environment but also on the human inhabitants. The number of natural disaster is growing together with the number of people who are migrating from one place to another place due to climate change. If the process is continued, between 50 million and 350 million climate migrant will be expected by 2050. The existing policies and institutional mechanism should be reviewed for better disaster responses. The primary responsibility goes to the government to address the immediate and future displacement crisis in Bangladesh. The capacity of the government and other national and international concerned authority has to plan and implement adaptive program to meet the challenge of climate change. Proper training, education, and awareness program has to be undertaken for the capacity building. Additionally proper implementation of the policies and guidelines needs to be ensured for better displacement of the person. Every attempt should be taken by the concern authority to find domestic solution to displacement, in the event that domestic solution is no longer viable. The international environmental law as well as international human rights law can play a vital role as appropriate mechanisms are crafted to support developing countries in their response to the adverse impacts of climate change. The international community has also taken the matter as an urgent and calls for political will to make it happen.

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Climate Change and Health in Colombia

Tam Tran, Salua Osorio Mrad, and Gilma C. Mantilla

Contents

Abstract

As the impacts of climate change become more widely acknowledged, federal governments are beginning to address the subject in the national agenda. However, the difficulty in determining the magnitude and impacts of climate change has led to challenges in policy-making. This chapter seeks to create a

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comprehensive understanding of how Colombia and the federal government have made important advances in implementing a climate change framework with a focus on health.

This chapter will provide context on the role and responsibilities of the government before discussing the climatic conditions of Colombia and how climate change is impacting the country, especially on the health sector. Such discussion will justify why climate change is a major current and future priority for the country. The chapter will then examine the existing climate change policy framework and ongoing projects that are targeted toward climate and health. This chapter will show that there is still a need to improve the capacities and interest of the public health research community by improving the evidence and knowledge about climate change impacts, vulnerability, and risk. Understanding Colombia's national circumstances will allow other countries and decision-makers to potentially use Colombia as an example to define their own health and climate change agendas.

Keywords
Colombia • Climate change • Health • Policy adaptation • Mitigation • Climate impacts

Introduction

With the annual carbon dioxide maximum having recently exceeded 400 ppm, the IPCC reports have agreed that climate change will likely impact society but there is a great deal of uncertainty on the extent and timing of such impacts. Developing countries currently and will continue to experience the most negative impacts. Many countries lack the necessary resources and do not have an existing framework to create federal policies to respond to climate change. Furthermore, it is anticipated that public health will be highly impacted by climate change but the health sector currently lacks the federal support and resources to create and tailor policies accordingly.

Climate change and health issues have recently become a large concern globally and they are starting to be addressed in many developing countries. A climate change policy framework, with a focus on health, will be provided on Colombia because of the progress that has been made within the country and by the government. Brief pertinent background information on the political structure of Colombia will be illustrated so context can be provided on the role and responsibilities of the government. The chapter will then discuss the climatic conditions of Colombia and how climate change is impacting the country, especially in the health sector. Such discussion will justify why climate change is a major current and future priority for the country. The chapter will then examine the existing climate change policies, with a focus on climate change and health policies, in Colombia where advances have been made.

The hope is that by illustrating existing federal policies in a developing nation, other developing nations may also learn and replicate the successes of Colombia's policies within their own respective countries. By demonstrating the progress that has been done within Colombia, the goal is that other countries may eventually use similar Colombia's climate change framework to define their own health and climate change agendas. Providing information on a government's current capabilities and how climate change impacts each nation is crucial because without such background, context cannot be provided to justify why federal policies should be prioritized or enforced.

This chapter utilized governmental documents, publications from major organizations, and scientific articles to discuss the current policies in Colombia. The authors of this chapter relied on peer-reviewed publications, when available, but this was not often possible because of the lack of available publications on the Colombian policies. The greatest efforts were thus made to utilize documents published by the Colombian government in an attempt to ensure accuracy on Colombia's status. By doing so, this allowed less limitation in illustrating the current political framework in Colombia.

Background

Despite contributing only 0.2 % of the total global carbon dioxide emissions, Colombia is considered highly vulnerable to the negative social, economic, and environmental impacts of climate change (Ideam 2010). Certain climate change impacts are already occurring in the country based on studies such as the Integrated National Adaptation Project (INAP) conducted by the Institute of Hydrology, Meteorology, and Environmental Studies of Colombia (IDEAM); the Institute of Marine and Coast Research (INVEMAR); the Corporation for the Sustainable Development of the Archipelago of San Andrés, Providencia, and Santa Catalina (CORALINA); and the National Institute of Health (NIH) (World Bank 2012). Colombia has been cited as a leader in developing climate change policies (Comstock et al. 2012).

Colombia is a party to the United Nations Convention on Climate Change and has signed and ratified the Kyoto Protocol (European Commission 2009). As part of its commitments to the Convention, Colombia published its First National Communication (NC-1) in 2001, identifying malaria and dengue fever/DHF as climate-sensitive diseases of primary concern (IDEAM 2001). The Second National Communication (NC-2) was published in 2010 and updated the greenhouse gases inventory, the climate change scenarios, and the national policies and plans associated with mitigation and developed a method to estimate vulnerability to compare the different sectors, ecosystems, and institutions (Ideam 2010). Colombia is currently developing the Third National Communication.

The main national environmental authority in Colombia is the Ministry of Environment and Sustainable Development (MEDS), which is responsible for the climate change agenda (MinAmbiente). The IDEAM, affiliated with MEDS, is responsible for producing and managing the scientific and technical information on the environment (IDEAM 2001). IDEAM is the country's leading agency for climate change and is responsible for producing United Nations Framework Convention on Climate Change (UNFCCC) documents and relevant supporting material (IDEAM 2001).

The main health authorities in Colombia are the Ministry of Health and Social Protection (MSPS) and the National Institute of Health (NIH). The Ministry is responsible for directing the health-care system and social protection through policies on health promotion, prevention, treatment, and rehabilitation (MinSalud). It is also responsible of the inter-sectoral coordination to develop the public health policy (MinSalud). The National Institute of Health (NIH), affiliated with the MSPS, promotes scientific research, innovation, and formulation of studies according to the public health priorities. NIH is the lead institution on the public health surveillance system (Ministerio de Salud y Protecciòn Social 2012).

Using governmental documents and scientific publications, this chapter will provide insight on how climate change impacts Colombia and health, and governmental actions on this subject. Background will first be provided on the climate in Colombia and how climate change impacts health.

Climate

Colombia is located on the equator and is thus affected by the intertropical convergence zone, ITCZ (Ideam 2010). The migration of the ITCZ is the dominant factor in controlling the annual hydroclimatic cycle and corresponds to the trade winds movement (Poveda et al. 2005). The average annual precipitation in Colombia is 3,000 mm but varies drastically in different parts of the country due to the geography and topography (Ideam 2010). While temperatures range from very hot to very cold, the temperatures show minimal seasonal variation at the same altitude (World Bank 2011b). Most of the climatic differences are due to the differences in elevation.

The spatial variability is controlled by Colombia's geography, such as the eastern Pacific and western Atlantic oceans, the Andes mountains, atmospheric circulation over the Amazon basin, and soil and vegetation moisture contrast (Poveda et al. 1999). The Choco jet, a westerly at 5°N, and the easterly San Andres jet at 12–14°N are low-lying jet stream that affects climate variability (Poveda et al. 2005).

ENSO, the El Niño Southern Oscillation phenomenon, is a major driver in the climate and the hydrological cycles at interannual timescales in the Pacific (Poveda et al. 2005). It has particularly strong impacts on the northern regions of South America (Poveda et al. 2005). During El Niño events, Colombia is more likely to experience droughts, reduced rainfall, and increased air temperature (Poveda 2009). During La Niña, Colombia generally experiences wetter conditions (World Bank 2011b). ENSO occurs later and is weaker in the east than in the western and central part of Colombia (Poveda 2009). ENSO affects the ITCZ in northern South America by causing a decrease in convection by a weaker land-sea thermal contrast and extra subsidence over the ITCZ (Poveda 2009). In recent years, from 2009 to

2011, El Niño caused the reservoirs for water supply to drop to critical levels, whereas La Niña resulted in heavy rainfall that led to landslides and major floods and maximized the capacity of reservoirs (Barriga 2011).

According to IDEAM, Colombia has five major climatic regions: hot (with elevations below 900 m below sea level), temperate (900–1,980 m), cold (1,980–3,500 m), high-altitude grasslands (the so-called paramos, 3,500–4,500 m), and areas of "permanent" snow (above 4,500 m) year (Colombia dashboard: climate baseline). Under the Holdridge classification, 60 % of the Colombia territory is warm humid, 8.9 % is warm dry, 7.65 % is warm very humid, 4.63 % is template humid, 4.13 % is template dry, 2.76 % is cold humid, and 2.17 % is very cold humid (Atlas climatológico de Colombia: Segunda Parte). The remaining categories do not exceed 1 % (Atlas climatológico de Colombia: Segunda Parte). The hot region experiences temperatures from 24 °C to 38 °C and alternates between dry and wet interannual seasons (World Bank 2011b). The temperate has an annual temperature range between 19 °C and 24 °C; there are two wet seasons, from April to June and October to December, and two dry seasons from January to March and July to September (World Bank 2011b). The cold zone has an average temperature range between 10 °C and 19 °C and the wet seasons are bimodal, occurring from April to May and September to December (World Bank 2011b).

Climate Change Impacts

In the last 20 years, the temperature has increased by 1 °C (Colombia overview). From 1974 to 1998, the temperature change in the Central Andes was 0.34 °C, 70 % greater than the average global temperature change (European Commission 2009). Precipitation has increased in Colombia by 5 % from December to February (World Bank 2011b). Precipitation is decreasing in the north while increasing in the south (Blanco and Hernández 2009). In central Colombia, rainy seasons have recently been occurring earlier, with positive anomalies for intense rainfall events and consecutive dry days (Colombia dashboard: climate baseline).

As aforementioned, climate change is currently and will further impact Colombia in the future. The Pacific Decadal Oscillation, PDO, is expected to enter a negative phase in the upcoming years (Barriga 2011). This will likely result in more frequent La Nina events and wetter than average conditions, thus prolonging the rainy period cycle (Barriga 2011). Extreme climatic events and variability are predicted to increase (Barriga 2011). The long 2005 drought period led to projections that the savannah region will expand in Colombia (European Commission 2009). Snow-covered regions are likely to completely vanish and over half of the moorland may disappear (World Bank 2009). This will result in a loss of natural resources, especially water (World Bank 2009). A simultaneous increase in the rainy season could result in higher risks of flooding (World Bank 2009). These climate change forecasts will be especially problematic for the future of Colombia because the country already suffers from water shortages and land instability in the Andes (Slunge 2008). Along with drastically affecting land settlements and economic activities, climate change is expected to negatively impact those in poverty and will thus challenge the country's Millennium Development Goal of reducing poverty (Côté et al. 2010).

Using 1971–2000 as a base period, climate change scenarios have projected an increase in the mean temperature of 0.13 °C per decade for 1971–2000 (Climate change). The multi-model ensembles have predicted that the average air temperature will increase to 1.4 °C for 2011–2040 and 2.4–3.2 °C from 2041 to 2070 and for 2071–2100 (Climate change). In the next century, the total amount of precipitation will reduce between 15 % and 36 % for much of the Caribbean and Andean regions and increase around the Pacific Region (Climate change). Predictions have indicated that there may be a rise of 40 and 60 cm of sea level in the Caribbean and Pacific Coasts, respectively, compared to the base period (Impactos del cambio climático del nivel nacional; World Bank (2013b).

Based on these results, the following socioeconomic sectors and natural systems were identified as the most vulnerable: costal zones, water resources, glaciers, highland Andean ecosystems and associated forest cover, soils and land undergoing desertification, the agricultural sector, and human health due to an expected increase in exposure to tropical vector diseases such as malaria and dengue (IDEAM 2001). INAP, based on the NC-1 results, identified areas of primary concern: high mountain ecosystems (notably moorlands), insular and coast areas, and human health (World Bank 2012). These topics were selected as topics of significant concern due to their high vulnerability to climate variation and their importance for human populations (World Bank 2012).

The INAP project has made several important advances in response to climate change by producing important results regarding water and carbon cycle in high mountain ecosystems; glaciological mass balance related to interannual climate events such El Niño and La Niña; planning models of land use that incorporate climate change impacts through an "Adaptive Ecological Territorial Structure" (EETA); the establishment of the system of observation of the oceans (GOOS) in the Caribbean based on the installation of physical and biological monitoring stations; supporting the implementation of a marine protected area in the area of Corales del Rosario, San Bernardo, and Isla Fuerte; development of a management system for managing groundwater reserves in the San Andres; and implementation of a monitoring system of coastal erosion (World Bank 2011a).

Climate Change Impacts on Health

Most of the evidence of the impact of climate and climate change on health is on communicable diseases, mainly vector-borne diseases (Epstein 1997). The information available in Colombia is regarding malaria, dengue fever, leishmaniasis, and leptospirosis. There are also some preliminary studies about acute respiratory disease (ARD). Recent information has been released in Colombia on how climate change impacts health so this chapter will provide an update on published information.

Malaria is a protozoal disease caused by infection with *Plasmodium* spp. and is transmitted to humans through the bite of an infected female mosquito, *Anopheles* species. Of the four known parasite species that cause malaria, three are found in Colombia: *Plasmodium vivax*, *Plasmodium falciparum*, and *Plasmodium malariae* (Blanco and Hernández 2009).

Malaria transmission is highly sensitive to climate conditions. Temperature is a significant driver and determines their reproduction and maturation rates for both the mosquito vector and the *Plasmodium* parasite (Blanco and Hernández 2009). The parasite is unable to develop in its vectors when ambient temperature is below 18 °C (Olano et al. 2001). Rainfall and humidity provide essential environmental characteristics for juvenile mosquito development (breeding sites) and adult survivorship (Blanco and Hernandez 2009; Wernsdorfer and McGregpr 1988). Consequently, it is expected that climate change will affect malaria transmission dynamics (Blanco and Hernández 2009).

Approximately 13 million Colombians live in regions with endemic malaria transmission (MSPC 1996, 2000, 2003a, b). Malaria incidence is mostly rural (Valero-Bernal 2006). The annual parasite index (total infectious/population at risk) increased from 6.2 (2008) to 7.9 (2009) to 11.48 (2010) to 6.3 (2011) (INS). Approximately half of malaria cases are concentrated in two states; 75 % of them are reported by 44 municipalities (World Bank 2011a). The Colombian Pacific coast (with an area of about 72,000 km^2 and almost 2.2 million inhabitants) typically concentrates 10-30 % of the total malaria cases in Colombia for the last 50 years, with 24 % in 2008 (Rodríguez et al. 2011). The Urabá-Sinu and Bajo Cauca region (43,400 km^2 and 2.5 million inhabitants) comprised of 60 % of total cases in 2010 and the Amazon-Orinoquia region concentrated nearly 8 % (Rodríguez et al. 2011).

Even though malaria is a highly complex multifactorial disease, some studies have demonstrated a significant relation between the occurrence of ENSO and the increase in malaria cases in South America (Barnston et al. 1997, Gagnon et al. 2002). Several studies on Colombia's nationwide malaria situation showed a significant association between ENSO and increases in the number of malaria cases (e.g., Poveda and Rojas 1997; Bouma et al. 1997; Poveda et al. 2001; Mantilla et al. 2009). Poveda and Rojas (1997) reported evidence of the association between malaria epidemics and the occurrence of the warm phase of ENSO (Poveda et al. 2001). Based on malaria morbidity profiles observed over the period from 1960 to 1992, Bouma et al. (1997) suggested that malaria cases are likely to increase by 17.3 % during El Niño years and by 35.1 % in the post-Niño years. Poveda et al. (2001) stated that the El Niño event intensifies the annual cycle of Colombia's *P. falciparum* and *P. vivax* malaria cases in endemic rural areas as a consequence of the concomitant anomalies in the normal annual cycles of temperature and rainfall. More recently, Mantilla et al. (2009) further reinforced these observations by showing that ENSO is a significant predictor of the number of malaria cases in Colombia, particularly in lowland regions along the Pacific and Atlantic coasts.

Other studies have also quantified projections in the number of expected malaria cases. In a study by Blanco and Hernández (2009), they used the IPCC scenarios to predict the climate change impacts on temperature and precipitation. Based on those scenarios, the study calculated the additional increase in malaria cases based on the 6-year disease period from 2000 to 2005 (Blanco and Hernández 2009). During this 6-year period, *P. falciparum* had 184,350 cases; for a 50-year scenario, cases are expected to increase by over 19,000 cases and nearly 57,000 cases over a 100-year scenario (Blanco and Hernández 2009). During the same 6-year period, *P. vivax* had 274,513 cases; for a 50-year scenario, cases are expected to increase by over 16,000 cases and over 48,000 cases over a 100-year scenario (Blanco and Hernández 2009).

According to the results of INAP (World Bank 2011a), the impact of temperature and precipitation varies from region to region. Temperature is the key determinant for malaria transmission in the Pacific zone, precipitation for the Orinoquia zone, and both temperature and precipitation for the Atlantic zone. Forecasts were made using dynamic models. In the medium term (2015), the model suggested increases of 6–15 cases per 1,000 habitants assuming constant socioeconomic and entomological conditions. For the long term, the model suggested a strong increase in the number of cases until 2040 where the prevalence starts to decrease.

Dengue is a viral and urban disease transmitted to humans through the bite of an infected female mosquito, *Aedes aegypti* (Padmanabha et al. 2012) The mosquito species are particularly susceptible to environmental conditions, an important factor in dengue transmission (CDC 2010). The viability and reproductivity of mosquitoes are dependent on temperature, precipitation, and humidity (CDC 2010). Higher temperatures have been noted to reduce the life cycle of the virus in the vector (CDC 2010). As temperature increases, mosquitoes will have a higher likelihood of transmitting dengue fever to humans (CDC 2010). Four dengue serotypes exist worldwide and Colombia is at risk for all four serotypes (WHO 2009).

The report conducted by Bello Pérez (2011) showed that 75 % of the national territory, located at altitude of 1,800 m, has conditions of temperature, relative humidity, and rainfall suitable for dengue transmission. This is distributed in 620 endemic municipalities with a total population of 23,607,414 people at risk. 80 percent of the disease burden is recorded in 100 endemic municipalities. Since its reemergence in the 1970s, dengue transmission has presented a wide geographic expansion and intensification in the Colombian territory. This phenomenon was especially evident during the last decade. There was an increasing trend in the number of municipalities where dengue cases were recorded annually, from 402 municipalities with endemic transmission in 1999 to 621 municipalities in 2009 (Vigilancia Rutinaria). In 2010 Colombia experienced the largest epidemic in the history of the country, with a total of 147,426 cases of dengue in total, 221 confirmed deaths, and a case fatality rate of 2.26 % (Vigilancia Rutinaria).

There are mix reports on the effect of temperature on dengue fever. It has been suggested that herd immunity, rather than temperature, is the limiting factor on transmission intensity (Blanco and Hernández 2009). Other reports have linked disease transmission to temperature. The larval mosquito matures over a specific temperature threshold and freezing temperatures will kill the eggs (Poveda et al. 2005). Moderately high temperatures can accelerate the larval stage, causing smaller mosquitoes that feed more frequently (Poveda et al. 2005). With climate change, temperature ranges are expected to shift geographically and may allow transmission of dengue fever into new locations. The aforementioned study by Blanco and Hernández (2009) included predictions on the additional increase in dengue fever based. During the 6-year period from 2000 to 2005 which was used as their base study, there was a total of 194,330 dengue cases recorded (Blanco and Hernández 2009). For a 50-year scenario, cases were expected to increase by over 41,000 cases and over 123,000 cases for a 100-year scenario (Blanco and Hernández 2009).

The INAP report (World Bank 2011a) included a summary of the dengue fever situation in Colombia. The use of climate and dengue models currently has limited impacts on controlling dengue fever. Colombia has focused on intervention strategies that focus on dengue vector production because it is easier to control the transmission dynamics. INAP uses a targeted approach to determine how climate change affects dengue fever in the country by understanding four key processes. First, INAP recognizes that water insecurity and high costs affect human behavior; improper storage due to instable conditions can lead to increased vector production. Climate change is expected to further increase the cost and instability of water, which will require people to have better water storage. Second, the density of people and displacement are significant considerations. Cities with more than 150,000 people constantly suffer dengue fever, suggesting that epidemics are amplified by high population density. Human migration between cities can spread transmission. Third, property size and precipitation affect dengue fever dynamics because close quarters increase the density of the population, thus causing a higher risk of human contact. Furthermore, living in cities with water storage containers reduces seasonal variation and changes how mosquitoes have seasonal production. Lastly, variation in temperature and height affects mosquito interaction. Overall models suggest that human adaptation to water uncertainty will have a larger impact on dengue risk for regions above 1,200 m and below 600 m compared to the intermediate regions. Larval mortality is generally greater at 24–26 °C than 20–22 °C or 28–30 °C. Currently, dengue fever activities are based on local health authorities. The present control activities for epidemics are often expensive because they require vector control resources and short-term intervention strategies, e.g., spraying insecticides during epidemics. While these methods have not been very effective, the increase in population immunity has led to reduced epidemics, creating a false sense of success. More effective control strategies will require more spatiotemporal adaptation to water insecurity access, a risk assessment of dengue fever, and connecting the ongoing work at a local and national level.

Leishmaniasis is caused by *Leishmania* species and is vectored by sand flies, the *Lutzomyia* species (Cardenas et al. 2006). Of the three forms of the disease, cutaneous comprises 95 % of reported leishmaniasis cases in Colombia (Valderrama-Ardila et al. 2010). The disease distribution can occur in different climates and habitats, with the Andean region having the highest disease rates (Valderrama-Ardila et al. 2010). Leishmaniasis has been linked to ENSO cycles in northeastern Colombia (Cardenas et al. 2006). During El Niño, the rate of incidence increases because of the dry conditions (Cardenas et al. 2006). In contrast, during La Niña, the rate decreases because of the wetter season (Cardenas et al. 2006). The number of cases reported in the country has increased significantly from 6,500 cases per year in the 1990s to over 16,000 cases per year by 2006 (Valderrama-Ardila et al. 2010). As the climate warms in the future, it is suggested that this will lead to ideal conditions for *Leishmania* development (Cardenas et al. 2006).

Climate variability has also been demonstrated to affect rodent-borne diseases in Colombia, including leptospirosis. Humans and susceptible animals acquire disease by contact with surfaces, water, or food contaminated with urine infected by the bacteria. The most common reservoirs are rats, dogs, wild animals, cows, and pigs. The incidence of leptospirosis depends on the environmental and climatic conditions influencing the dynamics of the rodent population, size, and behavior. In 1995, there was a significant outbreak of leptospirosis, in Colombia along the Caribbean coast (Cardenas et al. 2006; Pappas et al. 2008). From 1990 to 1995, the El Niño period was linked with a long drought period (Epstein 1997). However, the drought period ended with an extreme rainfall that marked the beginning of a La Niña period, which lasted from 1995 to 1996 (Epstein 1997). As a result, rodents left their burrows and caused an increase in leptospirosis outbreak (Epstein 1997).

For other diseases like acute respiratory disease (ARD), most of the information is from studies conducted in Bogotá by Alcaldía Mayor de Bogotá et al. (2011). The epidemic peak of acute respiratory disease develops between the months of March and June and is associated with phenomena like intensification of rainfall, changes in ambient temperature, and changes in the circulation of respiratory viruses. However, in the winter season of 2010, the torrential rains presented since June and became stronger in August and extended until November. This resulted in flooding in the rainy season, which began in August, and an increase in cases of ARD in Bogotá from this month was observed.

For other types of diseases in Colombia, the effect on climate change on health is inconclusive. There is the general belief among the health sector that climate can be associated with the increase in some diseases but further research will be required.

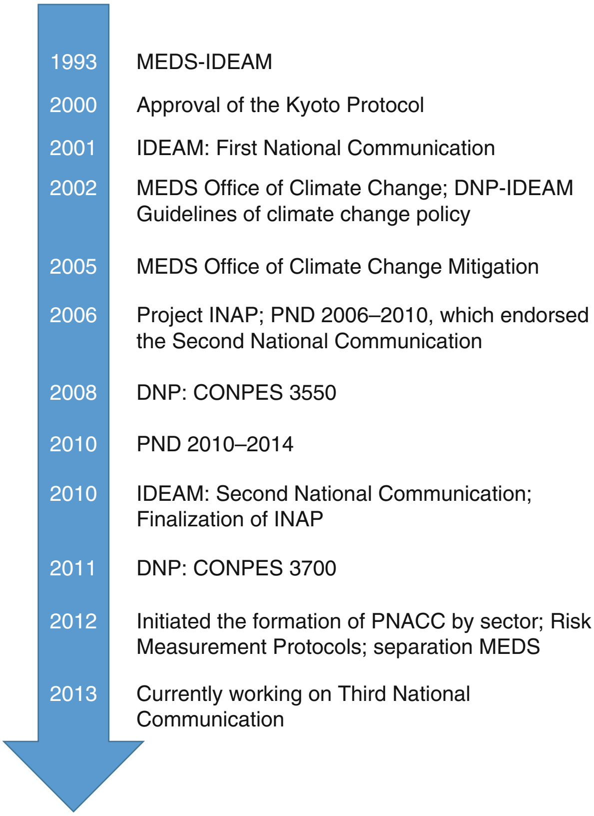
Policies on Health and Climate Change

In recognition that climate change will impact all sectors, the Colombian government is encouraging a multi-sectoral approach to programs and policies. A summary on climate change policies that are relevant to the health sector responding to climate change impacts will be provided as a framework (see Fig. 1).

Climate Change Policy Framework

Along with Colombia's international commitments, Colombia has made several advancements in linking policies with climate change in the National Development Plan (PND) from 2006 to 2010 and 2010 to 2014. The National Economic and

Fig. 1 Milestones in climate change adaptation and mitigation



Social Policy Council (CONPES) 3550 and 3700 articulated support for these plans and the the Basic Adaptation Concepts (ABC), included in PND 2010–2014, outlined the conceptual framework for climate change adaptation. These documents have provided the fundamental concepts for the different sectors, including health, when integrating climate change into their sector's agenda.

The PND of 2006–2010 endorsed the NC-2 and identified the necessity to support Clean Development Mechanism (CDM) projects, to seek options for reducing greenhouse gases (GHG) emissions, and to call for a national climate change policy and a comprehensive action plan on the issue (IDEAM 2001). The policy defined the institutional framework to coordinate the actions proposed therein (Plan Nacional de Desarrollo 2006–2010). The PND of 2010–2014 focuses its attention in relation to climate change in the following issues: National Plan for Climate Change Adaptation, Strategy for Disaster Financial Protection, Forest Policy and Avoided Deforestation (REDD+), and Colombian Strategy of Low Carbon Development (Sostenibilidad ambiental y prevención del riesgo).

The National Adaptation Plan 2010–2014 is coordinated by the Department of National Planning (DNP) with the support of the MEDS and IDEAM and is intended to reduce risk and socioeconomic impacts associated with climate variability and change (ABC: Adaptación bases conceptuales). It consists of four phases from 2012 to 2014 (ABC: Adaptación bases conceptuales). The Basic Adaptation Concepts (ABC), by the DNP, represents the first part under this plan and consists of four sections (ABC: Adaptación bases conceptuales). It is intended to build a conceptual framework for climate change adaptation for the country and establish guidelines to be followed during the formulation process for the different sectors and territories (ABC: Adaptación bases conceptuales). The first section explains the context that the National Adaptation Plan of Climate Change (NAPCC) was developed under, the second presents a conceptual framework that explains adaptation concepts, the third presents the main reasons to promote adaptation in Colombia, and the last defines the necessary guidelines for planned adaptation (ABC: Adaptación bases conceptuales).

CONPES 3550 was published on November 2008, with the main objective to define general guidelines that will strengthen the comprehensive management of the environmental health (DNP 2008). CONPES 3550 is oriented to prevent, manage, and control adverse health effects that result from environmental factors (DNP 2008). It serves as a basis for the formulation of the Comprehensive Environmental Health Policy (DNP 2008).

CONPES 3700 of July 2011, as stated by the DNP (2011), is a strategy to configure an inter-sectoral coordination mechanism to facilitate and promote the formulation and implementation of policies, plans, programs, incentives, projects, and methodologies in climate change. This will allow the inclusion of climate variables as determinants for the design and planning of development projects. CONPES 3700 is currently establishing the Climate Change National System (SNCC). The SNCC will consist of an Executive Committee of Climate Change (COMECC), a Financial Management Committee, a steering group, an advisory group, and four permanent subcommittees (sectoral, territorial, international affairs, and climate change studies and information production). The COMECC will be responsible for giving guidance and guide discussions on climate change at the national level and for ensuring the implementation and evaluation of policies, plans, and programs on the subject. Similarly, it will allow socializing at the highest level of government. The Financial Management Committee's main function will be to give technical feasibility and manage funding sources for projects submitted by the sectors, territories, or agent developers of adaptation and mitigation projects that do not have financial resources for its implementation. The permanent subcommittees will collect, analyze, and coordinate information, recommendations, and actions of the subjects in charge. They are to discuss and define studies and sectoral and territorial policies.

In addition to the national efforts, there are international efforts in Colombia as discussed by Côté et al. (2010). The Climate Change Mainstreaming Project was implemented between January 2009 and January 2010. It was implemented with assistance from UNDP, a 100,000 USD budget, and a four-person team. The project consisted of four stages. From January to March 2009, climate risks were assessed and a climate profile was produced; these were presented to the UN agencies and national entities to gain support. The second step occurred between April and July 2009 and resulted in the evaluation of risks and opportunities of climate change in national policy documents, development plans, UN plans, and UN projects, with an especially detailed analysis provided on the UN Development Assistance Framework (UNDAF). The third phase occurred during July, August, and November 2009; this organized public activities to present and gain feedback on previous efforts. This phase resulted in building capacities and the organization of a National Dialogue. The final phase, from September 2009 to January 2010, resulted in the publication of the Evaluation of Climate Risks and Opportunities in the Colombian UNDAF (2008–2012); in addition, it also involved correspondence with the IGCC and UN Agencies.

The project resulted in a risk and opportunity assessment of climate change in national policy, development plans, and UN projects (ALM 2011). Along with identifying stakeholders and UN initiatives in climate change issues and producing workshops, the Inter-agency Group on Climate Change of the Colombia UN Country Team was also created (ALM 2011). A UNDP methodology was produced for the evaluation of climate change risks and opportunities: "Quality Standards for the Integration of Adaptation to Climate Change into Developing Programming" (ALM 2011). It is intended to allow for the screening of climate change implications on projects and uses four "standards" (ALM 2011). This methodology was piloted in Colombia as a part of the Climate Change Mainstreaming Project and resulted in the recommendation of adaptation measures (ALM 2011). The principal aim for Colombia is to now launch a mechanism that will assimilate climate risks into a development assistance agenda (ALM 2011).

Using this framework, the Colombian Adaptation Plan will mainstream and integrate climate change considerations into the national agenda to develop capacities to face climate change challenge as further discussed by Côté et al. (2010). These adaptation measures are being implemented in high-priority regions, including the Caribbean islands and the Colombian mountain range, and in fundamental sectors, e.g., health and agriculture. Regional and local communities are now creating their own climate change adaptation plans, such as in the Coffee Belt and Capital Regions.

Climate and Health Policy

Climate change adaptation policies are targeted toward increasing research and building resilience (Ceron 2012). National public entities must incorporate an adaptation strategy to climate change into their agenda (Ceron 2012). The strategies should comply with the methodology defined by DNP, MEDS, and IDEAM (ABC: Adaptación bases conceptuales). In turn, the MEDS will support these public entities and require them to develop adaptation plans (ABC: Adaptación bases conceptuales). INAP is the most important health and climate change project and will be discussed in detail with brief insight on other ongoing governmental initiatives.

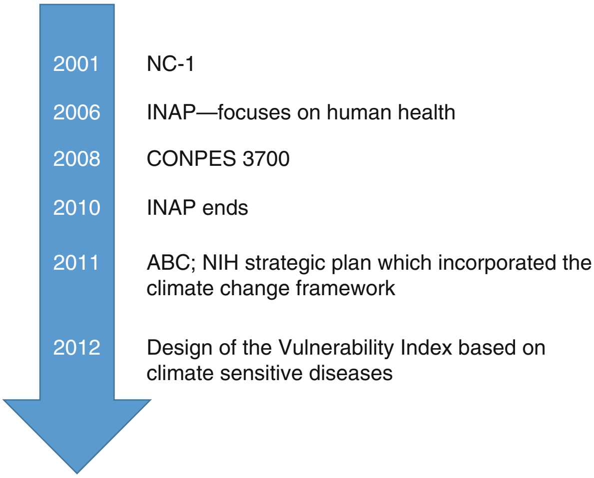


Fig. 2 Milestones in climate change and health policy

INAP was based on the TF Grant Agreement 056350 with 14.9 million USD (World Bank 2012). This project was partially founded by the GEF-World Bank and was coordinated by IDEAM and Conservation International-Colombia (Ideam 2010). This project had support from Accion Social, World Bank, IDEAM, Global Environment Facility, CORALINA, INVEMAR, and NIH (World Bank 2011a). The project was intended to span over the course of 5 years, from 2006 to 2011 (World Bank 2009). The objective of INAP was to support the Colombian government in implementing novel adaptation measures and policy options in anticipation of the impacts of climate change in high mountain ecosystems, Caribbean island areas, and human health (Ideam 2010).

INAP resulted in the opportunity for the health sector and the NIH to begin including climate change and the climate as a factor of consideration for the current and future status of health (World Bank 2011a). It allowed the incorporation of climate change into the NIH strategic plan 2011–2014 (World Bank 2011a). In addition, it provided the opportunity to participate in the CONPES document 3700 (World Bank 2012). INAP opened the discussions among the different sectors to face climate change impacts by allowing better understanding in the dynamics and effects of climate change (World Bank 2011a) (see Fig. 2).

Under INAP, Colombia proposed an Integrated Malaria and Dengue Surveillance and Control System, in order to avoid the potential negative impacts of climate change on human health in its territory (World Bank 2012). Some of the specific goals of this project included: (a) to strengthen the capability of the Colombian Institute of Hydrology, Meteorology and Environmental Studies to produce and disseminate continuous and reliable climate information relevant to the health sector and (b) to incorporate epidemiological, entomological, sociodemographic, and climatic data in the malaria and dengue surveillance system for proper understanding of malaria transmission and to regularly evaluate the spatiotemporal risk of infection in specific pilot sites and to develop locally adapted malaria and dengue control strategies (World Bank 2011a).

Furthermore, there have been efforts in Colombia on the vulnerability assessment front by including the most relevant findings from INAP as well as lessons from several other adaptation projects. The NIH is working on the development of a Vulnerability Index. The purpose of the vulnerability index is to guide the health sector adaptation plans, according to the DNP guidelines. The vulnerability index will allow identification and prioritization of adaptation measures. The conceptual framework is under construction and defines vulnerability as a function of sensitivity and adaptive capacity.

As stated by Ceron (2012), sensitivity consists of: (i) disease burden of climate-sensitive diseases and (ii) climate-sensitive risk factors associated to those diseases and that cannot be directly intervened by human action. A list of disease events that are sensitive to climate has been identified, including influenza, cholera, asthma, cardiovascular diseases, etc. A criterion was created to guide which diseases to focus in the Vulnerability Index in Colombia. The diseases must be a relevant public health burden in Colombia and there must be evidence that the diseases are impacted by climate. There must be at least 5 years of information from the surveillance system and information from other sources. It is also necessary that response to the disease is possible in the short and long term. The risk factors will be identified from literature review and expert focus groups. The diseases will also rate the sensitivity of the risk factor to the climate.

The adaptive capacity consists of governance and anthropogenic risk factors that are sensitive to climate, e.g., using bed nets with malaria (Ceron 2012). The conceptual framework should be consistent with DNP guidelines and its construction should include the participation of different sectors and institutions.

There are also local efforts to address the impacts of climate change on health, most notably in Bogotá, the capital city of Colombia whose population exceeds seven million inhabitants (DANE 2013a). As of 2011, several problems have been identified with climate change in Bogotá, including: increased risk of mortality due to the recurrence of extreme events, increase in diarrheal diseases due to changes in water supply, changes in patterns of viral circulation due to temperature and rainfall variation, changes in food security, effects of heat waves on morbidity and mortality, and increase in vector-borne diseases (Alcaldía Mayor de Bogotá et al. 2011). As a result, Bogotá has created a district environmental health policy that includes an intervention line related to climate change.

This intervention line has five main axes, as described by AlcaldÚa Mayor de Bogotá et al. (2011). First, there will be research development on the effects of climate change on health. Second, the plan will implement adaptation and mitigation processes to prevent further decline in health. Third, this will include the surveillance of events related to climate variability and change. Fourth, the plan will improve joint inter-institutional and inter-sectoral collaboration for the design of adaptation and mitigation measures. Lastly, the plan will strengthen community participation to reduce vulnerability.

Conclusion

Colombia has made important advances in implementing climate change adaptation and mitigation projects. Like many other developing countries, initial efforts and projects were concentrated in climate change mitigation and greenhouse gases inventory in response to the interests of information from UNFCCC. Even though these projects were responsible for introducing the topic, it is not until 2006 that the first national adaptation project (INAP) was developed. Since then, the federal government is slowly addressing the subject in the national agenda, which is being led by the National Planning Department (DNP).

The DNP has mainstreamed and integrated climate change into the National Development Plan. The department is also currently defining the strategy to configure an inter-sectoral coordination mechanism to facilitate and promote the formulation and implementation of policies, plans, programs, projects, and methodologies in climate change. This will allow the inclusion of climate variables as determinants for the design and planning of development projects. Given the prioritization process that will be required at the time of defining resources allocated for climate change adaptation, the leading role of DNP will be the key to successfully incorporating climate change adaptation into national policies.

Understanding and measuring vulnerability and risk to climate change is the first step in formulating and implementing adaptation plans. Although the initial efforts in Colombia were in identifying and implementing adaptation measures directly, the health sector has now focused on understanding and measuring vulnerability as one of the lessons learned from the INAP project. Despite the advances in Colombia, there is still a need to improve the capacities and interests of the public health research community and decision-makers and to further use climate information as another method of improving policies.

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Climate Change and Urban Development in Africa

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Contents

Abstract

Climate change poses a major threat to sustainable urban development in Africa. Changes in the frequency, intensity, and duration of climate extremes (droughts, floods, and heat waves, among others) will affect the livelihoods of the urban population, particularly the poor and other vulnerable communities

The views expressed here are the authors' own and not necessarily those of the United Nations Centre for Regional Development.

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who live in slums and marginalized settlements. Extreme changes in weather patterns will increase incidences of natural disasters and impact on all key sectors of the economy, including the urban economy, agriculture and forestry, water resources, coastal areas and settlements, and health. In Africa, where livelihoods are mainly based on climate-dependent resources and environment, the effect of climate change will be disproportionate and severe. Moreover, Africa's capacity to adapt to and cope with the adverse effects of climate variability is generally weak. This chapter examines the relations between climate change and urban development in Africa and looks at the role and effect of climate change on urban development. It also assesses the available policy options for adaptation and mitigating climate change effects in urban Africa.

Keywords
Africa • Climate change • Urban development • Adaptation and mitigation policies

Introduction

Climate change is one of today's emerging threats and challenges to humanity. The signs are visible, while its adverse effects are felt across both the developed and developing nations. The high incidences of flooding and intense rainfall (Trapp et al. 2007), drought and heat waves, cyclones, hurricanes, and the frequent erratic weather patterns, which have exacerbated poverty, displacement, and hunger among millions of people, are partly attributable to climate change (Pall et al. 2011). The term climate change has been defined as a statistically significant variation in either the mean state of climate or in its variability, persisting for an extended period (WMO 2012). The major causes of climate change include natural variations in sunlight intensity and human activities, which have led to an increase in greenhouse gases and a steady rise of the earth's temperatures.

Global warming, which entails a rise in the earth's temperature, is caused by the use of fossil fuels such as wood, coal, oil, and petrol, among other industrial processes that have led to a buildup of greenhouse gases such as carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons (IPCC 2007). Human activities that are related to biomass burning during shifting cultivation and domestic fuel are responsible for increasing greenhouse gases in Africa.

Besides rendering traditional agriculture across African countries less profitable, climate change has driven an unprecedented number of people into cities as they search for alternative livelihoods (Barrios et al. 2006). The resultant urban population increase has exerted pressure on urban services and resources such as urban space, urban water supply and infrastructure, and sanitation systems. Apart from posing a daunting challenge to urban planners and policymakers (Thynell 2007; Choguill 1999), climate change has become a major national, regional, and international problem and has limited human capabilities and undermined the international communities' efforts to attain the Millennium Development Goals (MDGs). Consequently, UNDP has declared climate change "the defining human development issue of our generation" (UNDP 2007, p. 1).

This chapter looks at the relationship between climate change and urban development and examines the impact of climate change on urban development in Africa. It also assesses available policy options for adaptation and mitigating climate change effects in urban Africa.

Climate Change and Its Impacts

The Intergovernmental Panel on Climate Change (IPCC) has declared that "warming of the climate system is unequivocal, as is now evident from observations of increase in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC 2007, p. 30). Consequently, warming of the climate will not only hinder the achievements of MDGs and sustainable development, but it will also increase the risk of violent conflicts and therefore adversely affect human security (Barnett and Adger 2007). Therefore, concerted efforts are required to tackle climate change since failure to address this challenge will result in diminished future prospects for humanity.

UNDP (2007) reports that average annual global temperatures have been rising by 0.7 °C (1.3 °F) since the industrial revolution. The report also notes the rapid rate at which CO_2 concentrations are increasing, leading to rising air temperatures. It is expected that with the rise in temperatures, droughts will be frequent as rainfall patterns change. In the next 100 years, climate-induced temperatures in Africa could increase by between 2 °C and 6 °C (Hulme et al. 2001). This will have adverse effects on agricultural productivity and food security. It will also mean less water for poor people, increased floods, and a rise in sea level, thereby posing a great threat to coastal regions and small island nations (Tacoli 2009). The rise in temperatures will also increase incidences of diseases such as malaria (in areas that were originally malaria free) and other communicable diseases.

Unfortunately, climate change disproportionately affects the poor and poor countries since it impacts on the very resources that the poor depend on, e.g., agriculture, forests, rivers, and lakes. Most importantly, poor countries are extremely vulnerable to the adverse effects of climate change due to their low physical and financial capacity to withstand the economic shocks triggered by climate change (Ward and Shively 2012).

Worsening climatic conditions, coupled with other factors such as political and ethnic conflicts, erosion of traditional safety nets, and the deteriorating physical infrastructure, besides the absence of general security in rural areas, have forced some people to migrate to urban areas, exerting further pressure on cities and compounding their socioeconomic problems (Choguill 1999). As centers of innovation, cities have the capacity and the technical know-how of dealing with climate change. Unfortunately, they are also the major contributors to greenhouse gases. City-based commercial, industrial, and domestic refrigeration facilities, for instance, discharge large amounts of gaseous emissions (Mosha 2011). There is therefore a need to critically examine the role of cities vis-à-vis the process of climate change and its impacts.

Urbanization and Urban Development in Africa

As people migrate from the rural areas to urban regions, global settlement patterns are gradually changing. For instance, in 2008, 3.3 billion people lived in urban areas, a number that is expected to reach 4.9 billion by 2030. Despite being the least urbanized continent in the world, Africa has the highest urbanization rate of 3 % per annum. In 2007, the African urban population was 373.4 million, a figure that is projected to reach 759.4 million by the year 2030. It is further projected that more than 1.2 billion Africans will be living in urban areas by the year 2050 (UN-HABITAT 2008).

Table 1 profiles the past, current, and projected urban population by subregion between 1980 and 2030. From the data, northern Africa and southern Africa are the most urbanized regions in Africa, while East Africa is the least urbanized (but nevertheless the most rapidly urbanizing region).

This rapid urbanization can be explained by both the natural growth of the urban population (the net excess of births over deaths in urban areas) and the rural–urban migration. On the other hand, Potter (2012) argues that rapid urbanization in Africa is due to the reclassification of small rural settlements as urban areas, while others (Zachariah and Conde 1981; Kelley 1991) argue that rural–urban migration is the main contributor to urbanization in Africa.

Rural–urban migration has been triggered mainly by both the pull-and-push factors (Barrios et al. 2006) as well as past development strategies adopted by African countries, including socialist-leaning development policies and structural adjustment programs, which are biased against rural and agricultural development (Hope 2009). A dismal consequence of these policies is that the nonagricultural population now exceeds the available nonagricultural employment, leading to *over-urbanization* (Hope 1998).

African urban economies (weakened by institutional problems such as extreme centralization, rampant corruption external factors, and unfair global trade practices) have failed to absorb the growing urban populations. As a result, in most cities of Africa, shanty towns and squatter settlements have developed along the periphery of the major cities (Mosha 2011). The poor who live in these areas face tremendous economic and social hardships since they do not have access to basic human services such as shelter, land, water, safe cooking fuel and electricity, heating, sanitation, garbage collection, drainage, paved roads, footpaths, street lighting, etc. (Tacoli 2009; World Bank 2009).

Urban areas in Africa host major government agencies and the private sector. These sectors contribute significantly to economic growth and create much-needed employment. According to the UN-HABITAT (2008), urban areas account for about 55 % of Africa's GDP. They therefore play a pivotal role in

Table 1 Percentage of African population residing in urban areas by subregion, 1980–2030

Region	1980	1990	2000	2010	2020	2030
Africa	27.9	32.0	35.9	39.9	44.6	50.0
Eastern Africa	14.4	17.7	21.1	24.6	29.0	34.8
Northern Africa	44.4	48.5	51.1	53.5	56.8	61.3
Southern Africa	31.5	36.7	42.1	47.1	52.3	57.9
Western Africa	29.2	33.0	38.4	44.1	50.1	56.1

Source: UN-HABITAT 2008

the production of goods and services, besides generating employment for the growing urban populations. Unfortunately urbanization in Africa is not accompanied with an increase in economic growth or improved living standards. This is a unique phenomenon, which the World Bank has called "urbanization without growth" (Fay and Opal 2000; Barrios et al. 2006). This pattern of "urbanization without growth" is the result of inappropriate policies that could not cater for properly managed and planned urban development. In developed countries, urbanization took root during the industrial revolution. At a time when there was "redundant" labor in the rural areas, there was an increase in demand for labor in urban areas (Potter 1995). The same cannot be said about the process of urbanization in Africa.

The process of urbanization in Africa is usually highly influenced by the movement of people displaced by drought, famine, ethnic conflicts, civil strife, and war. Acute levels of urban poverty and haphazard urban settlements are also common characteristics of urbanization in Africa. The poor live in poor neighborhoods where they face dire economic and social hardships. Most are uneducated and unskilled workers who have migrated to urban areas, encouraged by the push-and-pull factors associated with rural–urban migration.

Women and children are most affected according to Bartlett (2008), who says that children under the age of 14 are 44 % more likely to die due to urban environmental problems compared to the rest of the population. Bartlett further argues that "globally children under five are the victims of 80 % of sanitation-related illnesses and diarrhoeal diseases, primarily because of their less-developed immunity and because their play behaviour puts them into contact with pathogens" (2008, p. 505). The immediate challenges facing slums could be addressed through provision of basic services such as water, sanitation, and affordable housing. However, the long-term policy response should focus on economic growth, poverty reduction policies, and institutional capacity building, as well as on improved governance.

If properly managed and planned for, urbanization could be an engine of economic growth and industrialization. However, without a proper policy in place, urbanization will contribute to the rising urban poverty, proliferation of slums, regional inequalities, and degradation of urban infrastructure and environment. As a result, some African cities could become centers of crime and slum settlements rather than being engines of industrialization and economic growth.

The Impact of Climate Change on Urban Development in Africa

With erratic rainfall and frequent drought, rural dwellers in the continent find it very difficult to work on their farms. Therefore, they abandon their rural settlements and migrate to urban areas in search of better opportunities.

Unfortunately, the urban economy is weak and cannot absorb these environmental refugees (Barrios et al. 2006). It is estimated that by the year 2050, there may be as many as 200 million environmental refugees, people who are forced to move due to environmental degradation (Myers quoted in Tacoli 2009). The migrants are generally younger, landless men with few dependants (Tacoli 2009). Unfortunately, most of these migrants are lowly farmers with limited skills and education. They therefore cannot secure employment in the urban economic sector. Consequently, they almost always end up in slums and shanty towns.

Besides being the most marginalized, these settlements are also prone to flooding and landslides and have very limited or no social amenities such as running water, electricity, proper health care, and infrastructure. The largest slum in East Africa, Kibera, is located about 5 km southwest of Nairobi. It has about 250,000 people but has no proper sanitation and garbage collection systems, toilet, and infrastructure. Kibera is heavily polluted by human refuse, garbage, and other wastes, including human and animal feces, courtesy of the open sewage system and the frequent use of "flying toilets." This poor sanitation, combined with poor nutrition among residents, accounts for the many illnesses and diseases in Kibera.

Climate change will eventually lead to a rise in sea level and threaten small island nations and coastal areas, especially those located near the sea. With nine of the world's ten most populated cities located in the coastal zones, the effect of a rise in sea level on the population and ecosystem of these cities will be enormous (UNEP 2005). The major and direct impact of sea-level rise on coastal ecosystems will be erosion, submergence, and increase in salinity (Armah et al. 2005). It is estimated that more than 600 million people (10 % of the world's population) live in coastal regions that have an elevation of up to 10 m (about 2 % of the world's land area) above the seal level. Out of this, 360 million live in urban areas (13 % of the world's urban population) and about 247 million live in low-income countries (McGranhan et al. 2007). With the rise in sea level, coastal towns will be susceptible to cyclones, typhoons, hurricanes, and floods. It is projected that a 3–4 °C rise in temperature will expose between 134 and 332 million people to coastal flooding (UNDP 2007).

Desertification due to drought and man's actions, especially in the Saharan and Sahelian environment, results in sand and dust storms that could affect urban communities in many ways. Apart from the inconvenience and the disruption of transport and communications infrastructure, the increased risk of health-related problems such as respiratory diseases will continue to plague the continent.

Many African cities will experience severe water shortages as the ravages of climate change, especially due to persistent droughts, continue to deepen. Large cities such as Lagos, Nairobi, Dar es Salaam, and others have a permanent water crisis. Unfortunately, women and children have to bear the burden of walking long distances in search of water. Assuming that current levels of investment in the sub-Saharan African urban water supply and sanitation continue over the next 20 years, as many as 300 million people in African cities will be without proper sanitation; and 225 million will be without potable water supply by 2020 (World Bank 1996).

Besides the physical hazards from floods, droughts, and hurricanes, health-related risks will be on the rise as impacts of climate change bite deeper. Heat stress and respiratory distress from extreme temperatures might combine with air quality decreases to create higher mortality in urban areas. Changes in temperature, precipitation, and/or humidity will result in water- and vector-borne diseases. Less direct risks are expected as well; these include negative effects on livelihoods, food supplies, the psychological state of people, or access to water and other natural resources. The urban populations exposed to disease, such as dengue fever and malaria, already killing people in sub-Saharan Africa, are spreading to urban centers located in previously safe higher latitudes and altitudes (Wilbanks et al. 2007). The highland cities of Nairobi and Harare are a case in point (IPCC 2007).

The geographical distribution of some infectious diseases will be altered, as warmer average temperatures permit an expansion of the area in which malaria, dengue fever, filariasis, and other tropical diseases are likely to occur. It should be noted that many of these health risks are already evident among most urban populations of Africa, even in the absence of full-blown effects of climate change, and are related to such factors as age, gender, socioeconomic status, and access to health services. Extreme weather events will likely create new health hazards and disrupt public health services, thereby leading to increased disease incidences.

Infrastructure in urban areas is already showing evidence of destruction due to climate impacts such as flooding and sea-level rise. Some of the most vulnerable infrastructures include industrial plants; equipment for producing and distributing energy; roads, ports, and other transportation facilities; residential, institutional, and commercial properties; and coastal embankments. The economic consequences of these impacts are severe. For instance, in Uganda, the record-breaking rains of 1997 destroyed 40 % of the country's 9,600 km feeder road network. Similarly, between 1997 and 1998, a prolonged drought in the Seychelles led to the closure of the Seychelles Breweries and the Indian Ocean Tuna Company (Mosha 2011).

Rather than alter existing infrastructure, cities would probably choose to abandon it and relocate in upland areas at a cost of billions of dollars. People and jobs will be forced to relocate, and land use will change dramatically.

Adaptation and Mitigation Policies: Implications for Urban Development in Africa

Urban governments play a critical role in climate change adaptation and in mitigating (reducing) greenhouse gas emissions. They however need a supportive institutional, regulatory, and financial framework, backed by their highest decision-making organs. In addition, low- and middle-income nations need the backing and full support of international agencies (Satterthwaite 2007).

Emission of GHGs is one of the major policy issues that need to be addressed (APF 2007). Urban authorities in Africa should have in place policies aimed at reducing carbon emissions, but this should be reciprocated by a commitment to the reduction of global greenhouse emissions. For these policies to be effective, there must be incentives that recognize the development needs of urban authorities. Africa has legitimate energy needs, hence the problem of carbon emission in her urban centers. Policies encouraging clean energy technologies should be formulated and encouraged through capacity building and financial support from national governments. International partnership should also be established in a bid to bolster these efforts.

Most African urban centers are located within the tropics or subtropic regions where solar energy and hydropower are abundant. Policies encouraging development of Africa's vast solar energy potential and hydropower should be enacted. The World Bank and the African Development Bank Clean Energy and Development Investment Framework should be fully implemented as a mitigation measure.

To mainstream adaptation to climate change in urban areas, the strategy should be a continuous process, which addresses both current climate variability and extremes and future climate risks. Africa's urban authorities should take actions that link climate change adaptation to disaster risk management.

A number of African countries such as Botswana, South Africa, Uganda, and Kenya have put in place national policies for disaster management that address issues such as prevention, mitigation, preparedness, response and recovery, and development (Mosha 2011). In Uganda, for instance, the government has created a climate change unit within the Ministry of Water and Environment to coordinate all climate change concerns and spearhead policy formulation in the country (Magezi 2011). At the local and urban authority levels, cities such as Cape Town have developed a municipal adaptation policy (MAP) that includes proper management and control of water supplies, storm management, bushfires, and coastal zones (Hope 2009). Similarly, the city of Durban has also came up with a climate change adaptation strategy that includes human health, water and sanitation, coastal zones, food security and agriculture, infrastructure, and cross-sectoral activities.

Many African countries have now recognized that policies on climate change adaptation and mitigation need to shift from a purely environmental concern to addressing a growing threat to sustainable development. Managing both current and future climate risks should be an integral part of development processes at both the national and regional levels and should involve a cross-sectoral approach that is reflected in the budget, thus the need for greater attention by ministries of finance and national planning.

Urban authorities in Africa should adapt to climate change impacts through:

- Increased efforts to improve access to climate data
- Investment and transfer of technologies for adaptation in key sectors

- Developing and implementing best practices for screening and assessing climate change risks in development projects and programs
- Mainstreaming climate factors into development planning and implementation
- Providing significant additional investment for disaster prevention

For Africa to adapt to the impacts of climate change, it will need development partners to deliver on their commitments. Assisting Africa's development through its largely unexploited hydropower potential will help to meet her objective of increasing energy access while limiting GHG emissions. Compensation for avoiding deforestation could also be introduced so as to limit GHG emissions, but this will require an understanding of the factors that encourage deforestation. Incentives to landholders could also be considered in a bid to discourage deforestation.

Policies that build on existing strategies to support adaptation to climate change are among the most likely to succeed. Growing evidence suggests that mobility, in conjunction with income diversification, is an important strategy for reducing vulnerability to environmental and non-environmental risks (Tacoli 2009).

Some of the climate change problems envisaged include drought, desertification, land degradation, floods and the rise of sea level. It is projected that between 75 and 250 million people in Africa will not have access to freshwater by 2030 (IPCC 2007). Climate stress usually overlaps with other factors in determining migration duration and composition. It is therefore important that socioeconomic, political, and cultural factors are integrated into the adaptation policies.

The high vulnerability of urban systems and their impact on climate can be reduced through adaptation and mitigation measures based on known technology and design methodology. To counter climate change disasters, African urban authorities must have preparedness programs and plans, ingredients often lacking in most African cities (WMO 1994).

African urban centers located along the coast and river deltas (or estuaries) are highly exposed to flooding due to their proximity to the sea (e.g., Free Town, Alexandria, Cairo, Beira). In this regard, mitigation measures required include designing and building appropriate flood shelters, improving and expanding sewerage and drainage systems, and putting in place an information system on climate change effects and responses (WMO 1994).

Governance is an important element in climate change risk exposure. Urban authorities with limited incomes or assets are the most exposed. This is because they lack quality infrastructure and have poor disaster-preparedness provisions for planning and coordinating disaster response. Besides, the extent to which the poor can buy, build, or rent "safe" housing in "safe" sites and the degree to which the local government creates an enabling environment for local civil-society action to address these issues are limited (Satterthwaite 2007). Most urban authorities in Africa cannot afford the requisite cost of reducing the impact of climate change.

Climate change health adaptation and mitigation measures required in African urban centers include putting in place an information system that profiles air conditions, observation networks and programs, and impact assessments and predictions. Bioclimatic GIS can be a useful tool in urban planning and design and can be used in predicting climate change impact on mortality.

In terms of the impact of climate change on planning and architecture, there is need to take into account proper use of materials and architectural detailing, as well as drafting plans that maximize on outdoor spaces. Climate-sensitive designs should be done in a way that protects the environment from pollution. Architects and planners should use widely available knowledge and information on climate, while urban climatologists need to simplify the language in which climatic data is availed to planners and architects. Planning and building codes should be made public and their objectives clearly set out. A specific design guide that incorporates climate information is required.

In a nutshell, the key to adaptation is competent, capable, and accountable urban governments that understand how to incorporate adaptation measures into aspects of their work and departments (Satterthwaite 2007).

Conclusion

Climate change is both a threat and a challenge to Africa. Climate variability affects agricultural production and influences hunger, health, access to water, and consequently food security and poverty in the continent. Prolonged droughts and floods, which are associated with climate change, impact negatively on the livelihoods of farmers, making traditional agriculture across Africa less profitable. This in turn results in a number of people from rural areas migrating to cities in search of better livelihoods.

The increased urban population in turn exerts pressure on urban services and natural resources such as urban space, urban water supplies, infrastructure, and sanitation systems, creating a challenge for urban planners and policymakers. The effects of climate change must therefore be factored into African countries' urban policies and unequivocally address the current and emerging urban challenges, especially the rapid urbanization, poverty, informality, and safety.

While Africa is the most vulnerable and most affected by climate change, it has the weakest coping mechanism and less financial and human resources. The support of the international community to help Africa build the requisite capacity to adapt to climate change is therefore very crucial.

Municipal governments and urban authorities should design policies that are sensitive to energy saving, fewer sprawls, and climate-resilient infrastructure, especially with respect to drainage, flood control, housing, sanitation, transport, and water distribution systems. In the USA, for example, the 2005 Energy Policy Act creates policies and incentives for developing renewable energy. The Act aims to enhance and expand domestic energy production. Brazil's government instituted the Incentives for Small Hydro Facilities policy to exempt small hydro facilities (those which produce less than 30 MW) from paying financial compensation for the use of water resources.

To encounter the expected climate change disasters, urban authorities must also have preparedness programs and plans. Urban policies in Africa should also emphasize and focus on new techniques and methods of seasonal prediction, early warning systems, monitoring, and risk management.

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Climate Change Governance: Emerging Legal and Institutional Frameworks for Developing Countries

Martin Oulu

Contents

Abstract

Climate change is a relatively new governance area in which policy and practice tend to precede theory or advance simultaneously. Establishing effective legal and institutional frameworks is crucial to its management. This chapter conducts a comparative analysis of the climate change governance frameworks of four developing countries, namely, the Philippines, Mexico, South Africa, and Kenya, all of which have enacted or propose climate change legislations,

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strategies, and related institutional structures and have decentralized governments. These are contrasted with the UK, the first to globally enact a framework climate change law. The results indicate that despite being time- and resource consuming, enactment of stand-alone framework climate change legislation is preferred over piecemeal amendments to relevant laws. Another key finding is the overwhelming adoption of mainstreaming as an important approach to managing climate change. Moreover, both adaptation and mitigation are considered equally important, mitigation being seen as a function of adaptation. This disabuses the notion that developing countries do not or should not focus much on mitigation. Institutionally, establishment of (often) a new high-level cross-sectoral climate change coordinating institution domiciled in the office of and/or chaired by the head of state is common. Such institutions offer general policy guidance and are supported at lower levels by an advisory panel of experts and a technical administrative secretariat. Procedures to ensure clear coordination between the central and devolved governments are in many instances outlined. Climate finance sources and management strategies are mixed. Sharing of experiences and strong support for national climate change legislations under ongoing post-Kyoto negotiations are recommended.

Keywords
Climate change • Governance • Policy • Legal and institutional frameworks • Developing countries

Introduction

Warming of the climate system is unequivocal as per the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007). Atmospheric carbon dioxide concentration recently hit the 400 parts-per-million mark. While developing countries' contribution to the greenhouse gas (GHG) emissions is negligible, they suffer most from the impacts of climate change because they lack the necessary institutional, economic, and financial capacity to cope (Huq et al. 2003). The vulnerability, coupled with the pressing need to grow their economies in order to reduce poverty levels, has traditionally underlined many developing countries' focus on adaptation efforts at the expense of mitigation. The situation is however steadily changing as many now strive to reduce their emissions by integrating emission reduction strategies into regular socioeconomic policies in pursuit of low-carbon development paths (cf. Reid and Goldemberg 1998). Their motivations are myriad: (i) mitigation is seen as a function of adaptation, that is, it offers opportunities for enhancing development and boosting adaptive capacity, (ii) opportunity to leapfrog into newer low-carbon technologies, (iii) promise of access to international climate finance, and (iv) the ideological commitment to show leadership.

The crosscutting nature of climate change has seen mainstreaming being widely advocated as an important approach to its management (cf. Oulu 2011).

Mainstreaming is the integration of climate change vulnerabilities or adaptation into some aspect of related government policy (IPCC 2007). Its potential benefits, dimensions, and assessment criteria have been extensively discussed (cf. Huq et al. 2003; Klein et al. 2007; Lasco et al. 2009; Mickwitz et al. 2009) and implementation guidelines published (cf. UNDP-UNEP 2011). It can be operationalized *horizontally* by different policy sectors or departments, *vertically* at different hierarchical administrative levels, and *internationally* by embodying multilateral cooperation (Persson and Klein 2008). The three dimensions highlight the multilevel and complexity of climate change governance. Nevertheless, addressing climate change is ultimately a local-scale affair. While international efforts are crucial, it is individual countries which determine relevant policy by translating both local and global goals into either adaptation or mitigation actions. Doing so requires effective national climate change policies, legislations, and institutions. In fact, advancing domestic climate legislations can help create the necessary conditions for an international deal (Townshend and Mathews 2013). Some even consider creation of durable regulatory frameworks and institutions as more important than the choice of particular programs (Stavins 1997). Yet, even as literature places governance at the center of future adaptation and mitigation efforts, many national governments have paid little attention to legislations and institutions (Agrawal and Perrin 2009).

This chapter conducts a comparative analysis of the climate change governance structures of four developing countries with decentralized government systems, namely, the Philippines, Mexico, South Africa, and Kenya. In particular, it focuses on the legal and institutional frameworks with the aim of identifying emerging best practice. These are contrasted against the UK, a developed country and first globally to enact a framework climate change law. The UK is often touted as having both the "hardware" (institutions) and "software" (necessary knowledge) (Persson 2004), key ingredients in dealing with climate change. The chapter is organized into five sections. After the Introduction, section "Climate Change Governance: Role of Law and Institutions" examines the role of law and institutions in climate change governance. The individual country governance structures are analyzed in section "Individual Country Governance Frameworks," while section "Synthesis of Emerging Climate Governance Best Practice" provides a synthesis of the emerging legal and institutional frameworks. Section "Concluding Remarks" makes some concluding remarks.

Climate Change Governance: Role of Law and Institutions

Governance is a fuzzy concept with many definitions but no consensus. Some view governance as a political process of setting explicit societal goals and intervening in their achievement, translating into a generic term for the coordination of social actions rather than an antonym for government (Fröhlich and Knieling 2013). Three dimensions of governance are distinguished (Homeyer 2006; Herodes et al. 2007): policy (the nature and implementation of policy instruments), politics (actor constellations), and polity (institutional properties), each with a continuum of possible subdimensions. The vagueness of the term nonetheless allows for its use in a variety of disciplines and contexts. In climate change, it encompasses a broad range of forms of coordination of adaptation and mitigation characterized by cross-boundary, multilevel, multi-sector, and multiagency settings as well as long-term challenges and uncertainty (Fröhlich and Knieling 2013). Climate change is, essentially, a "wicked" problem (Balint et al 2011) or "super wicked problem" (Lazarus 2008). Its enormous interdependencies, uncertainties, and conflicting stakeholders lack a single problem formulation or solution. Moreover, the longer it takes to address it, the harder it becomes, while those best positioned to do so have the least immediate incentive to act, making its governance a complex reality. The field is also still a relatively new area in which policy and practice tend to precede theory or advance simultaneously. Lack of middle-range adaptation theories to help frame policy debates and absence of comparative empirical studies to support policy interventions are glaring challenges (Agrawal 2008).

Domestic climate change legislation has traditionally been viewed as something for governments to enact after an international agreement has been reached to support implementation. However, there is a growing global trend in which individual countries, states, or even cities are unilaterally implementing their own climate change regulations. While this could be attributed to frustrations with stalled United Nations (UN) climate agreements, it is also indicative of a growing recognition of the crucial role of domestic legislations and measures (Stavins 1997). By disregarding the so-called matching principle (cf. Butler and Mecey 1996), these countries are rebutting the skeptics' claim that it is self-defeating for a country to act alone on climate change. Apart from the possibility of regulation at lower jurisdictional level triggering regulation at a higher (international) level (Engel and Saleska 2005), the inclination toward domestic climate change legislations also signal a "portfolio" approach in which a suite of different plans spread risks across individual countries (Vance 2012). Many developing countries are beginning to implement national emission reduction actions, fully aware that it is in their self-interest to do so and make their economies climate resilient even in the absence of a global deal or sufficient action by developed countries (Townshend and Mathews 2013). Some have even suggested that combined emission savings from such national actions may be greater than those attained by industrialized countries (Reid and Goldemberg 1998). Clearly, the ongoing Durban Platform negotiations should involve a formal recognition of and active support for the advancement of national climate legislation.

Modes of environmental governance are variously categorized. Regulation or *command and control* is the most common approach. Literature is also awash with many types of "new" or "newer" policy instruments (NEPIs) which include market-based instruments, eco-labels, and voluntary agreements (Jordan et al. 2005). They have been hailed as able to offer cost-effective alternatives, provide dynamic incentives for technological change, address distributional equity concerns, and raise revenue (Stavins 1997; EEA 2005). Despite the "frenzy" surrounding the apparent popularity of NEPIs, regulation still dominates. Barring noncompliance may be the only means of ensuring environmental integrity. Importantly, many of the NEPIs require legislation to be effective (EEA 2005; Jordan et al. 2005; Herodes et al. 2007). But legislation also has its challenges and the nature varies greatly. Subsequent amendments, limited budgets, financial conditionality, delays in operationalizing regulations, vested interests, and simple nonenforcement can render a seemingly strong legal mandate mere symbolic aspirational statement. Successful climate change legislations must therefore be simultaneously flexible in certain respects and steadfast in others (Lazarus 2008). They should incorporate institutional design features that significantly insulate implementation from vested political and economic interests. Such design features should include precommitment strategies which deliberately make it hard, though not impossible, to change the law in response to emerging concerns and insights, as well as those intended to keep the statute on course over time. Examples include requirements for consultation with other agencies, scientific advisory committees, and stakeholders; judicial review provisions; and preemption triggers that accommodate competing interests while exploiting the resulting tension to further climate change policy.

Institutions are systems of rules and decision-making procedures that give rise to social practices, assign roles, and guide interactions (Gupta et al. 2010). Categorized into public, civil society, or private sector, institutions are humanly created formal and informal mechanisms which shape social and individual expectations, interactions, and behavior initiatives (Agrawal and Perrin 2009). They play a major role in assisting countries anticipate and respond to climate change by structuring the distribution of risks, constituting and organizing incentive structures, and mediating external interventions into local contexts. Effective adaptation-enhancing institutions encourage the involvement of a variety of perspectives and actors, allow continuous learning and behavior change, and can mobilize resources (Gupta et al. 2010). Fragmentation, conflicting mandates, and capacity challenges plague many developing country institutions.

Individual Country Governance Frameworks

The Philippines

Climate Change Vulnerability and Government Structure

The Philippines is an archipelagic country in Southeast Asia classified as lower middle income by the World Bank. Due to its location in the Pacific Ring of Fire, it is prone to earthquakes and active volcanoes and is ranked highest in the world in terms of vulnerability to tropical cyclone occurrence (Yumul et al. 2011; RoP 2011). The country lies within the Intertropical Convergence Zone (ITCZ), a source of heavy rains and storms. Its geography and location therefore puts it at a high risk from sea level rise (Lofts and Kenny 2012). The Philippines and similar small island developing states are particularly vulnerable to global environmental change (Pelling and Uitto 2001; IPCC 2007; Yumul et al. 2011; Guillotreau et al. 2012). Their disproportionate natural resource dependency and extensive coastlines expose them to high climate change risks. The country's GHG emission in 2000 was 21,767.41GgCO_2e (RoP 2011).

The 1987 Philippine Constitution provides for a unitary multitiered government (Diokno 2009; Manasan 2009). The country is divided into 15 administrative regions and two additional autonomous regions, Mindanao and Cordillera. The president is the head of state and government, and the bicameral legislature is made up of the Senate and the House of Representatives. Devolved local government units (LGUs) consist of provinces each subdivided into cities, municipalities, and barangays – the smallest political unit. They have authority over natural resource management, pollution control, and environmental protection but are under considerable supervision by higher-level government in areas like budgeting and legislation.

Legislative Framework

Well aware of its particular vulnerability to climate change, the Philippines developed the comprehensive *Climate Change Act of 2009*, the first in the developing world and second globally after the UK. The Act aims to "mainstream(ing) climate change into government policy formulations, establish(ing) the framework strategy and program on climate change, creating for this purpose the Climate Change Commission" (RoP 2009, p. 1). The unequivocal intent to systematically mainstream climate change is noteworthy, suggesting that the mainstreaming mantra is slowly finding its way from academia into policy and, hopefully, practice. Both adaptation and mitigation measures have since been implemented through formulation of a Framework Strategy and Program on Climate Change (2010–2022) and the National Climate Change Action Plan (2011–2028), but with no emission reduction targets. Interestingly, the Framework Strategy "treats mitigation as a function of adaptation" (RoP 2010, p. 17). That is, it recognizes the mutually beneficial relationship in which mitigation strategies offer opportunities for enhancing adaptive capacity. The close interrelation between climate change and disaster risk reduction (DRR) is particularly evident in the Philippines. As such, the Climate Change Act integrates DRR into climate change initiatives, while the Disaster Risk Reduction and Management Act 2010 considers disasters as inclusive of climate change impacts (RoP 2010).

Institutional Framework

Climate Change Commission

The Climate Change Act (2009) establishes the Climate Change Commission (CCC) as the sole policy-making body charged with coordinating, monitoring, and evaluating climate change-related programs and action plans. It is chaired by the president of the republic and is administratively located in the Office of the President, making it very high level. This arrangement has several potential advantages. First, it enhances the profile of and puts climate change firmly and high up on the national agenda. Second, it is a way of procuring and maintaining the political will and commitment to implement climate change actions by the executive. From a political ecology perspective, climate change is inherently political (cf. Eriksen and Lind 2009). Making the president by law the head of the premier climate change outfit does not automatically translate into political will. Rather, political competition potentially does the trick. That is, the incumbent will be motivated to bring to bear his or her political and executive powers on climate change programs as a way of endearing oneself to the electorate. The Act can, therefore, by design or default, create climate change champions out of the president, the executive, and the ruling political party or coalition. Champions play a critical role in rallying necessary support and educating the public on climate change (cf. Roberts 2008). Third, although enhancing mainstreaming, listed as the first function of the Commission, should essentially happen at all levels, the higher the better as this allows greater possibility of integration at lower political and administrative levels. The high-level status of the Commission gives the convening powers necessary to integrate climate change horizontally and vertically across all levels of governance.

The Commission is made up of three other Commissioners who must be climate change experts. It is supported by a broad-based, cross-sectoral, and cross-departmental *advisory board* with representatives from relevant government ministries, local government, academia, the private sector, and civil society. Involvement of key stakeholders enhances the quality of climate change policies and their implementation but could also pose a challenge as it might prove difficult to reconcile the myriad of interests at play. Nevertheless, the Commission is mandated to meet once every 3 months or as often as deemed necessary, an arrangement which could help resolve any deadlocks in good time. Infrequency of meetings can impede the functioning and effectiveness of institutions.

The day-to-day running of the Commission is assigned to a secretariat, the *Climate Change Office* headed by the Commission's vice chairperson. In addition, a *Panel of Technical Experts* provides technical advice to the Commission in climate science, technologies, and best practices for risk assessment and enhancement of adaptive capacity. Surprisingly, the experts are to be permanently employed by the Commission. Without a clear definition of what particular "technical advice" they are to provide and for how long, it would be cost-effective to make the panel ad hoc. Nevertheless, the panel of experts incorporates a science- and evidence-based approach to climate change management.

Other Institutions

Government ministries and agencies are assigned specific roles based on their core mandates in the Climate Change Act. For example, the Department of Education is to integrate climate change into the primary and secondary education curricula, while government financial institutions are required to give preferential financial packages for climate change-related projects. Some of the specified roles and responsibilities are, however, quite restrictive and do not allow for an innovative interpretation of their mandates with regard to climate change. Local government units (LGUs) are at the forefront in formulating, planning, and implementing local climate change action plans. The Joint Congressional Oversight Committee is to monitor implementation of provisions of the Act and recommend any necessary legislation.

Climate Finance

Climate finance is crucial to addressing climate change. All relevant government agencies and local government units are to allocate adequate funds from their annual budgets for the implementation of their respective climate change programs and plans. No special fund is set up although the Commission is authorized to accept financial support from local and international sources. No carbon trading schemes are to be set up or funding expected from such, a cautious move given that they have not benefitted the intended developing countries and their underlying logic for net emission reductions has been questioned (cf. Mulugetta 2011; Reddy 2011; Bond et al. 2012). International funds, though often necessary, should complement, not replace, domestic resource mobilization.

Mexico

Climate Change Vulnerability and Government Structure

Mexico, a Latin American country bordering the United States of America (USA), is categorized as upper-middle-income economy by the World Bank (2013). Its GHG emissions are quite high, about 616 Mt CO_2e in 2010 excluding land-use change (Höhne et al. 2012) and ranked eleventh globally (Vance 2012). Its climate is projected to become drier and warmer, with several hydrological regions highly vulnerable to decreased precipitation and higher temperatures (IPCC 2007). This makes major economic support sectors vulnerable to climate change (Liverman and O'Brien 1991). For example, the agricultural sector employs more than a third of its growing population, yet only one-fifth of the country's cropland is irrigated. Rainfed agriculture supports subsistence farmers and provides most of the domestic food supply. Frequent droughts already reduce harvests and jeopardize food and energy security. About one-fifth of Mexico's electricity is hydroelectric, hence susceptible to reduced water levels. Significant mismatch between water supply and population will see increased problems for cities and industrial production.

Mexico is a three-tier federal government with 31 relatively autonomous states and a federal district which encompass Mexico City (Rodríguez and Ward 1994; Lankao 2007; Höhne et al. 2012). The president is the head of the federation and government, the bicameral legislature (Congress) is made up of the upper and lower chambers, while the judiciary is divided into federal and state systems. Unlike other Latin American countries, the president is directly elected for a single 6-year term. From the state, lower levels of devolution include the municipality (*municipio*) and municipal council (*ayuntamiento*). Although the devolved units are supposedly autonomous, the hegemonic nature of the ruling party often muzzles such autonomy, for example, in financial resources (cf. Höhne et al. 2012).

Legislative Framework

The General Law on Climate Change (Ley General de Cambio Climático) was enacted in 2012, making Mexico the most recent country and third globally to enact a framework climate change law. The law seeks to facilitate the transition to a competitive low-carbon emission economy by consolidating the institutional framework across the three levels of government, regulation of adaptation and mitigation actions, and promotion of research, innovation, and technology transfer. It fulfills Mexico's Cancún pledge to voluntarily reduce its emissions to 30 % by 2020 and 50 % by 2050 (based on 2000 baseline), conditional on international financial support. This is in addition to generating 35 % of the country's electricity from renewable sources by 2024. The 2020 target is considered the most stringent for a developing country, and Mexico is the only developing country so far to set itself an absolute reduction target by 2050 (Höhne et al. 2012). Mechanisms for gradual establishment of market-based instruments and emission trading are included (IDLO 2012). The General Law of Ecological Balance and Environmental Protection (LGEEPA), Mexico's framework environmental law, was amended in 2011 to incorporate some climate change provisions, including the authority of environmental agencies to formulate and execute mitigation actions (Ruffo and Vega 2011). However, the enactment of the comprehensive General Law on Climate Change has incorporated and harmonized many such provisions.

Institutional Framework

The General Law on Climate Change establishes an institutional framework that emphasizes the need for a transversal, cross-sectoral approach to climate change and the critical importance of wide stakeholder participation (IDLO 2012). They include the following.

Intersecretarial Commission on Climate Change (Comisión Intersecretarial de Cambio Climático, CICC)

Originally administratively established in 2005 (Höhne et al. 2012), the CICC became embedded in the 2012 climate change law. Charged with formulating national climate change policies, coordinating actions across the federal government, and ensuring mainstreaming and participation of key stakeholders, the CICC is composed of several relevant government ministries. Similar to the Philippines' Climate Change Commission, the CICC is chaired by the president of the federation who may delegate this function to the minister responsible for environmental matters. It could not be established if the CICC is administratively located in the Office of the President. As already discussed under section "Institutional Framework" of the Philippines, making the president by law the chairperson and therefore directly the head of the premier, the climate change coordinating institution has positive ramifications for climate change management. Again, mainstreaming is clearly stated as one of the key objectives of the Commission and the law. The CICC is to have several permanent Working Groups, including one on Reducing Emissions from Deforestation and Forest Degradation (REDD). Deforestation is a major source of GHG emissions in Mexico and therefore an appropriate target area. Linked to the CICC is the *Council on Climate Change* (Consejo de Cambio Climático, CCC), a permanent consultative body comprised of representatives from the private sector, civil society, and academia. Its objective is to foster broad stakeholder participation, collaboration, and support for climate change policies and actions (IDLO 2012). It can be equated to the Philippine's Climate Change Commission's *Advisory Board*.

National Institute of Ecology and Climate Change (Instituto Nacional de Ecología y Cambio Climático (INECC))

INECC is the main public agency responsible for climate change policy development and evaluation (IDLO 2012). Specifically, it is to prepare, conduct, and evaluate the national climate change policy; design market-based instruments; prepare an emissions inventory; and build scientific and research capacity. Its management is under a governing board comprised of heads of several ministries and chaired by the sectoral minister responsible for environmental matters. It has a director general appointed by the president and chairperson of the CICC. The INECC's functions and composition are similar to the Philippine's Climate Change Office (CCO). However, the similarity of its functions to and unclear relation to the CICC might create institutional conflict if clear coordination and communication mechanisms are not put in place.

Other Institutions

The National System for Climate Change (Sistema Nacional de Cambio Climático, SNCC) is a permanent communication and coordination mechanism between the federal government and devolved governments. Made up of the CICC, CCC, INECC, state governments, LGU representatives, and the Congress, it is aimed at promoting the cross implementation of the national climate change policy (IDLO 2012). In a decentralized system such as in Mexico, clear coordination and communication between different governance levels are very crucial for the effective implementation of a crosscutting policy issue like climate change. The Evaluation Committee (Coordinación de Evaluación, CE) reports to the SNCC and is an expert body made up of the head of INECC and representatives from the scientific, academic, and technical communities charged with periodically and systematically evaluating progress on implementation of aspects of the climate change law.

Climate Finance

The General Law on Climate Change establishes a *Climate Change Fund* (Fondo Para el Cambio Climático) aimed at sourcing and channeling funds from public and private sectors, at both national and international levels (IDLO 2012). This is in addition to annual budgetary allocation and proceeds from carbon trading. The CICC is legally mandated to establish an emission market, including a regulating agency (Höhne et al. 2012).

South Africa

Climate Change Vulnerability and Government Structure

South Africa is the only African country whose contribution to global warming is significant (Chevallier 2010) due to its energy-intensive, fossil-fuel-powered economy. The 2000 estimate was 435 million tons of CO_2 (Letete et al. 2009). A greater warming trend has been observed throughout the continent since the 1960s (IPCC 2007). Even under very conservative emission scenarios, it is predicted that by mid-century the South African coast will warm by around 1–2 °C and the interior by around 2–3 °C (RSA 2011). Declining rainfall patterns and increased frequency of extreme climate events such as droughts and floods are projected (Maponya and Mpandeli 2012; IFRC 2011). These changes will significantly affect human health, agriculture, and other water-intensive economic sectors such as mining and electricity generation. Moreover, a large number of South Africans live in conditions of chronic disaster vulnerability such as fragile ecologies or marginal areas (RSA 2005). The severe June 1994 floods in Cape Town's historically disadvantaged Cape Flats exposed the country's disaster soft underbelly.

South Africa is a federal government comprised of a three-tier devolved system: national, provincial, and local. The president is the head of state and government. The Parliament is made up of the National Assembly and the National Council of Provinces. Each of the nine provincial governments is allowed to make provincial laws and may adopt their own constitution. Three categories of local governments (or municipalities) exist (Pasquini et al. 2013): metropolitan, local municipalities, and district. Many of their responsibilities have important implications for climate change management. The constitution also recognizes the role of traditional leadership. All the three levels of government must observe and adhere to the principles of cooperative government. As is expected, the country's decentralization has its challenges (cf. Koelble and Andrew 2013).

Legislative Framework

South Africa does not have a framework climate change law. The *National Climate Change Response White Paper* (2011) is the key policy document guiding climate change management. It sets mitigation targets that should collectively result in a 34 % and a 42 % deviation below its "business as usual" emission growth trajectory by 2020 and 2025, respectively, conditional on international financial and technological support (RSA 2011). It also outlines the institutional and other planning frameworks. Existing legislations, especially those dealing with disaster risk reduction and general environmental regulation, e.g., the Air Quality Act 2004, are also relevant to adaptation and mitigation efforts. To ensure that climate change is fully mainstreamed into the work of all three spheres of government, all government departments and state-owned enterprises are to regularly review their policies and plans (RSA 2011). The *Disaster Management Act of 2002* definition of "disaster" as a progressive or sudden, widespread or localized, and natural- or human-caused occurrence (RSA 2003) can be interpreted as inclusive of climate change. The White Paper also considers DRR as short-term adaptations to climate change and acknowledges the existence and crucial role played by the Disaster Management Act. Overall, South Africa seems to have no immediate intention of enacting a stand-alone framework climate change law. Implementation of the actions stipulated in the White Paper will, where necessary, be implemented through piecemeal changes to relevant existing legislations and regulations. This is at variance with all the other countries analyzed. Mainstreaming is however at the core of its climate change management efforts.

Institutional Framework

Unlike the Philippines and Mexico, South Africa's climate change institutional framework is fragmented. Several institutions are responsible for various aspects of climate change, many of which overlap, thus creating possibilities of conflict. Most are also not anchored in any law and lack administrative capabilities or budgetary allocation.

Interministerial Committee on Climate Change (IMCCC)

Established in 2009, the IMCCC is to oversee all aspects of the implementation of the climate change policy. In justifying the need for the IMCCC, the White Paper states that "the strategic, multi-faceted and crosscutting nature of climate-resilient development requires a coordination committee at executive (Cabinet) level that will coordinate and align climate change response actions with national policies and legislation" (RSA 2011, p. 36). This illustrates the necessity of a high-level cross-sectoral institution with convening powers as is similarly applied by the countries analyzed so far. However, contrary to the above statement and at variance with the other developing countries, the IMCCC is to be chaired by the minister responsible for the environment rather than the president or Cabinet secretary. Additionally, technical, analytical, and administrative capacity to the IMCCC will be provided by a secretariat based in the sectoral Department of Environmental Affairs (DEA). Though interministerial, the arrangement makes the IMCCC less high level relative to the rest of the countries analyzed. The net effect is a lowering of the profile of climate change in the national agenda and potential challenges in integrating climate change across government. In many governments the world over, ministries of environment are rarely viewed as "powerful" based not only on their perennial paltry annual budgetary allocation but also because of the late entry of environmental issues on the national agenda, many countries having only established environmental ministries after the 1992 Earth Summit in Rio de Janeiro, Brazil. Environmental ministries thus lack the political clout, financial muscle, and convening powers necessary to effectively coordinate and mainstream a crosscutting issue such as climate change across government. Moreover, Giordano et al. (2011) view the IMCCC as merely an information platform which does not include all relevant ministries, especially that of finance.

Forum of South African Directors-General Clusters

Forum of South African Directors-General (FOSAD) was established in 1998 to enhance integration of crosscutting issues within the overall policy and implementation framework and address identified coordination weaknesses such as lack of alignment between different governmental planning cycles and between the central and devolved units (RSA n.d.). Mirroring the main Cabinet committees, they are to provide strategic leadership for the national climate change response actions. However, their structure and functioning has been criticized as potentially inappropriate for the prioritization of climate change issues (Giordano et al. 2011).

Intergovernmental Committee on Climate Change (IGCCC)

Established in 2008, the IGCCC's role is to operationalize cooperative governance in the area of climate change by bringing together the relevant national, provincial, and municipal departments under the principle of cooperative government. It fosters information exchange and consultation. However, lack of representation of the Department of Cooperative Governance and Traditional Affairs (COGTA), inability to provide practical assistance in policy development or implementation, and lack of an administrative budget or structure (Giordano et al. 2011) potentially weaken its effectiveness.

Other Institutions

The National Committee on Climate Change (NCCC), which is to be formalized into an advisory council *with statutory powers* and extended responsibilities beyond the current communication function, is one of two mechanisms set up to coordinate activities and consult with key stakeholders (RSA 2011). Its upgrade could remedy its current lack of legal backing, a secretariat, and regular budget and lack of executive power (Giordano et al. 2011). The second stakeholder coordination mechanism is the National Economic Development and Labour Council (NEDLAC) which brings together the government, business, and labor unions. The environment, including climate change, is a concurrent function between the provincial and national government. Each province is to develop its own climate response strategy, and municipalities are to integrate climate change considerations and constraints into their development plans and programs. To make clear local governments' mandate and assign them specific climate change-related powers, COGTA is to review relevant policies and legislations. Parliament is to review legislation and determine the legal requirements to support the existing or proposed institutional and regulatory arrangements, while line ministries and agencies are to integrate climate change into their policies and programs.

Climate Finance

By necessity, South Africa's climate finance strategy comprises a comprehensive suite of measures, including market-based ones, to create and maintain a long-term funding framework for mitigation and adaptation actions. In the short- and medium-term period, a transitional climate finance system and interim climate finance coordination mechanism are to be established, the nature of which is not outlined. In the long term, however, climate change actions will be integrated into the fiscal budgetary process of all the three tiers of government.

Kenya

Climate Change Vulnerability and Government Structure

Kenya has experienced increasing temperature trends over most parts of the country for the past 60 years (GoK 2010a). The time series of annual and seasonal rainfall for the standard seasons of December–January–February, March–April–May, June–July–August, and September–October–November indicates a neutral to slightly decreasing trends. The effects of the observed climatic changes include a reduction in the glacier on Mt. Kenya, variability in weather patterns, and frequent, prolonged, and severe drought and flood conditions (NEMA 2008). Kenya's natural resource-based economy makes it particularly vulnerable to climate change. Agriculture is mainly rainfed, while tourism largely depends on wildlife and the ecosystem, both highly susceptible to climate change (cf. GoK 2010a; Kameri-Mbote and Odote 2011; NEMA 2008; Mutimba et al. 2010). Some estimates put the future net economic costs of climate change at 2.6 % of GDP per year by 2030 and doubling by 2050 (SEI 2009).

The new (2010) constitution makes Kenya a presidential republic with a two-tier decentralized system of distinct and interdependent central and 47 county governments (GoK 2010b). The president is the head of state and government and together with the deputy president, attorney general, and several Cabinet secretaries form the Cabinet. The bicameral Parliament is made up of the National Assembly and Senate. The Senate represents the interests of the counties, while county assemblies have legislative powers. County governments' functions have a bearing on climate change management and include county planning, controlling air pollution, natural resource and environmental conservation, agriculture, health, transport, and trade.

Legislative Framework

Kenya, like South Africa, is yet to enact a framework climate legislation. However, Kenya has made strong indications of its intention to do so in the near future. The country's climate change governance scope is encompassed in various policy and regulatory frameworks interrelated to its natural resources (Mutimba and Wanyoike 2013). This analysis will focus primarily on the National Climate Change Response Strategy 2010 (NCCRS), National Climate Change Action Plan 2013–2017 (NCCAP), and, briefly, the Climate Change Authority Bill 2012. The NCCRS was developed in 2010 with the aim of achieving a prosperous and climate change-resilient Kenya. It admits that "the integration of climate information into Government policies is important… (but) the same has not been adequately factored into most of the sectors of the country's economy including government development policies and plans" (GoK 2010a, p. 6), an endorsement of mainstreaming. It outlines an enabling policy, legal, and institutional framework. It recommends the development of a comprehensive climate change policy which should be translated into a climate change law by either strengthening existing legislations or developing a new stand-alone law (GoK 2010a). Despite being time-consuming and expensive, the NCCRS prefers an entirely new climate change law.

Launched in March 2013, the NCCAP operationalizes the NCCRS. It covers, among others, low-carbon development strategies; adaptation and mitigation options; climate finance; and an enabling policy, legislative, and institutional framework intended to enhance mainstreaming. The actions are premised on their contribution toward achieving Kenya's long-term development goals in addition to intermediate benefits such as improved livelihoods, attracting international climate finance, as well as demonstrating global leadership (GoK 2013). It further commits all government ministries, departments, and agencies to play a role in mainstreaming climate change across their functions and processes. No emission reduction target is set. Rather, priority low-carbon development areas and options are outlined. In keeping with the NCCRS, the NCCAP recommends development of a coherent stand-alone climate change policy to, among others, provide guidance on (i) the envisaged legislative framework to be established through a climate change law and (ii) the specific sectoral legislative amendments that will enable full implementation of the NCCAP's priorities. It reaffirms "the need to enact a *stand-alone framework climate change law* to facilitate the necessary direction, coordination, policy setting and high-level political prioritization in order to *mainstream* climate change across government functions" (GoK 2013, p. 100). The stand-alone climate law is to be accompanied by a series of sectoral legislative and regulatory amendments through either an omnibus bill or a number of separate legislative amendments in order to bring sectoral legislation in harmony with the framework climate change law.

The Kenya Climate Change Authority Bill, 2012, is a private member's bill presented to the Parliament in April 2012. Some of its proposals are at variance with those of the government which consider it a parallel effort (GoK 2013). Developed mainly by the civil society under the aegis of the Kenya Climate Change Working Group, the Bill seeks to establish a Climate Change Authority and provide a framework for mitigation and adaptation (GoK 2012). A Climate Change Trust Fund is also proposed. The Bill is, however, not comprehensive since beyond the proposed institutional framework, it covers very little else. It is evident from the NCCAP that the government has sidestepped the Bill and is focused on enacting an entirely new stand-alone framework climate change law. It seems that the proposals in the NCCRS and more specifically the NCCAP are the official Government of Kenya position on climate change. Consequently, the proposals in the Bill will not be considered any further.

Institutional Framework

The NCCRS considers a dedicated climate change institution as important in establishing a coordination instrument to ensure that all cross-sectoral activities match the overall vision of a prosperous and climate change-resilient Kenya (GoK 2010a). But its proposed institutional structure gives the sectoral ministry responsible for the environment a dominant role, with all the key institutions placed under it. The potential lack of effectiveness of such a sectoral and non-high-level institutional arrangement is already discussed under section "Institutional Framework" of South Africa. In summary, the National Climate Change Secretariat (NCCS), which was instrumental in developing the NCCAP, was established. In addition, the National Climate Change Steering Committee (NCCSC) was charged with gathering and collating information from various stakeholders, while the existing cross-sectoral National Climate Change Activities Coordination Committee (NCCACC) continued in its advisory capacity. Perhaps recognizing the potential weaknesses of the NCCRS proposal, the NCCAP proposes a radically different institutional framework intended to achieve high-level oversight and policy guidance, mainstream climate change, involve county governments and stakeholders, and enhance technical and scientific analysis capabilities (GoK 2013). The following institutions proposed in the NCCAP will most likely receive the necessary legal backing with the eventual enactment of a stand-alone climate change legislation.

National Climate Change Council (NCCC)

The proposed NCCC will be responsible for policy direction, coordination, and oversight across government. Consistent with similar institutions in the Philippines and Mexico, it will be located in the Office of the President and, therefore, high level. Although initial proposals (in which the author was involved as a consultant) involved making the president of the republic the chairperson of NCCC, the government eventually settled on the secretary to the Cabinet. Reporting annually to the Parliament, it has representatives of both the national and county governments as in the UK's Committee on Climate Change (see section "Institutional Framework" of the UK). Interministerial and interagency, the NCCC represents a wide cross section of stakeholder interests from public, private, academia, research, and civil society. The mandate, location, and composition of the NCCC accord it the necessary political clout, convening, and resource mobilization powers necessary to adequately champion and effectively mainstream climate change across government, both national and devolved. The NCCC will be supported by a technical *National Climate Change Secretariat* located within the sectoral ministry responsible for climate affairs. Its functions will include continuous revision of climate policy, proposal of relevant legislation, and program implementation. It may have decentralized structures at the county level to collect and collate climate change data.

Other Institutions

The ministry in charge of national planning is to spearhead integration of climate change into planning processes. One way will be through installation of climate change desk officers in all line ministries. The National Environment Management Authority (NEMA) remains the Designated National Authority (DNA) on the Clean Development Mechanism (CDM) and the National Implementing Entity (NIE) for the Adaptation Fund. County governments will have climate change functions coordinated and supported by the National Climate Change Secretariat (NCCS). A Climate Change Resource Center hosted by the NCCS is to become the one-stop shop for Kenya's climate change information and knowledge.

Climate Finance

A Kenya Climate Fund (KCF) located within the ministry responsible for finance intended as a vehicle for mobilizing and allocating both international and domestic financial resources toward climate change activities is proposed. The public sector's capacity to efficiently and effectively absorb the expected funding, scaling up access to international carbon markets and possible establishment of a carbon trading platform, as well as improving the "investment climate for climate investment" are some of the proposed climate finance strategies. Climate change funding will also be prioritized in the annual budget by creating climate change line items and coding them for ease of tracking.

The UK

Climate Change Vulnerability and Government Structure

The UK was the first country globally to enact a framework stand-alone climate change legislation in 2008. A developed country, the UK has a long, even intimate, history with GHG emissions based on its role in igniting the industrial revolution and the transition to the current fossil-fuel economy, the "anthropocene" (cf. Crutzen 2000). The warming trend throughout Europe is well established (IPCC 2007). The UK's first Climate Change Risk Assessment indicates both positive and negative impacts of climate change on production systems such as agriculture, forestry, and fisheries and key economic sectors such as tourism and energy (DEFRA 2012). The UK is a parliamentary democracy with a constitutional monarch. While the prime minister is the head of government, the queen is the head of state. The Cabinet is made up of the prime minister and several secretaries of state. Some power is devolved to Scotland, Wales, and Northern Ireland which are in charge of local environment, health, education, and transport.

Legislative Framework

Response to climate change in the UK has been varied (cf. Hulme and Turnpenny 2004). The first attempt to enact legislation aimed at reducing GHG emissions was through the *Climate Change and Sustainable Energy Act 2006* which sought to promote renewable energy and compliance with GHG emission-related building regulations (UK Govt. 2006). The Act was not comprehensive, lacking in areas such as adaptation, emission trading, and enabling institutional structures. A new comprehensive *Climate Change Act 2008* was therefore enacted. It sets a legally binding 2050 emission target of at least 80 % lower than the 1990 baseline, establishes an institutional framework and emission trading schemes, and makes provisions for adaptation (UK Govt. 2008). It also amends and harmonizes relevant existing legislations and regulations. While the legally binding emission reduction target is an obligation under the UNFCCC, the attention given to adaptation illustrates the need to plan for and build adaptive capacity even by developed countries.

Institutional Framework

Committee on Climate Change

The *Committee on Climate Change* is to give *advice* to the government and its agencies, including the devolved units. It is composed of a chairperson and five to eight members jointly appointed by the national authorities, i.e., the secretary of state and Scottish, Welsh, and Northern Ireland ministers responsible for climate change affairs. Cumulatively, the Commission must have experience in or knowledge of a set of expertise or *knowledge areas* crucial to a holistic understanding and management of climate change. The Committee appoints a *chief executive* and may establish several subcommittees, but with a *mandatory* adaptation subcommittee. It makes regular progress reports to the Parliament.

Other Institutions

Implementation of the advice and recommendations of the Committee on Climate Change are entirely left to the central and devolved governments. The Parliament plays its oversight role by receiving regular progress reports, while the Committee is required to involve the public and other stakeholders in carrying out its functions. Unlike the developing countries analyzed, the Climate Change Act 2008 does not provide for any resource mobilization strategy since requisite resources are to be included in the relevant implementing agencies' annual budgets.

Relation to Developing Countries' Frameworks

The UK's enactment of a stand-alone climate change law is in tandem with that of most of the developing countries analyzed. Institutionally, the UK adopts a lean structure. Relative to the developing countries, the composition, appointing authority, and apparent administrative independence give the impression that the Committee is not high level. However, this might not necessarily be the case given the UK's unique system where the executive, just like the Committee, is accountable to the Parliament. That all government agencies must seek and consider its advice further raises its profile and potential buy-in for its recommendations. However, the Committee's role is limited to advice, and its membership is expert led rather than stakeholder based. Such a scientific approach potentially depoliticizes and reduces conflicts within the Committee but can be criticized for ignoring the positive aspects of stakeholder participation. Its success is thus contingent on a high degree of public faith in science for policy.

The direct inclusion of representatives of devolved units in the premier climate change institution is shared by the UK and Kenya. This could be attributed to their unique devolved systems which wield significant powers and autonomy. The arrangement enhances interpretation and smooth implementation of climate change goals at the local levels and is worth emulating. Overall, despite being the pioneer in enacting framework climate change legislation, it is hard to tell to what degree the UK has influenced the legal and institutional structures of the other developing countries.

Synthesis of Emerging Climate Governance Best Practice

Climate change governance frameworks are still evolving. The few but growing number of countries that have proposed legal and institutional structures provide insight which can guide other countries. The foregoing comparative analysis has revealed certain emerging best practice, summarized below, which forms elements of a climate change governance structure developing countries can reproduce, expand, or tailor to their domestic sociopolitical situations.

Enactment of New Stand-Alone Framework Climate Change Legislation

Except South Africa which has no immediate intention of enacting a stand-alone framework climate change law, all the rest either have done so or have unequivocally demonstrated their intention to do so. Two key factors seem to favor such a framework law: (i) the "wicked" nature of climate change requires strategies and policy instruments that go beyond what existing sectoral legislations might have been conceived to deal with, and (ii) the nature and degree of potential amendments to existing sectoral laws are so extensive that they are best captured in a comprehensive stand-alone legislation. The UK's experience of initially opting for the limited *Climate Change and Sustainable Energy Act*, *2006*, before settling on the more comprehensive *Climate Change Act*, *2008*, illustrates this point.

Mainstreaming Is Key to Climate Change Management

Mainstreaming of climate change into policies, legislations, and programs is widely advocated in literature as a more effective approach to tackling climate change. Yet, its uptake and application in laws and institutions are yet to be fully assessed. This comparative analysis provides some empirical evidence that mainstreaming is finding its way into policy and planning instruments from academia. All the countries assessed embrace mainstreaming and commit to integrating climate change through various strategies. This calls for early targeted training on how to mainstream climate change at different levels and constant monitoring and evaluation of applied strategies.

Mitigation Actions Are as Domestically Beneficial as Adaptation

The need to grow their economies in order to lift their growing populations out of poverty has traditionally been used to explain a seeming focus on adaptation at the expense of mitigation by many developing countries. However, empirical evidence from this analysis indicates that most of these countries now view mitigation as a function of adaptation, basing their emission reduction actions on envisaged benefits or "win-win" outcomes. These are generally packaged as low-carbon development strategies or pathways. Apart from the urge to demonstrate global leadership, a possible frustration with international efforts, and jab at the developed countries for perceived lack of commitment, such benefits include job creation and access to new technology and international finance. The distinction between mitigation and adaptation actions is increasingly becoming blurred. Many mitigation actions have adaptation benefits and vice versa.

High-Level Climate Change Institution

The dominant trend across the countries analyzed is the establishment of a *new* high-level cross-sectoral climate change institution with representation from a wide cross section of stakeholders. Charged with overall advice, policy guidance, coordination, and oversight, its high-level status emanates from being chaired by the country's president, or secretary to the Cabinet, and location in the Office of the President (OP) or Cabinet Office, or both. Remember most of the countries are presidential systems. The UK and Kenya go a notch higher by including representatives of the devolved units in this premier climate change institution. Such an arrangement puts climate change high up on the national agenda, enhances political commitment, and promotes mainstreaming. Complementing the climate change institution is an advisory board made up of academia, private sector, civil society, and other special interests. A dedicated secretariat to oversee the technical aspects of the climate change policy and handle day-to-day affairs completes the institutional structure.

Clear Roles, Responsibilities, and Coordination Mechanisms

Clearly defining the roles and responsibilities of institutions with regard to climate change reduces conflicts and leads to effective resource use. However, in doing so, the ability to innovatively interpret such roles and responsibilities should be allowed by not being so prescriptive. For institutions, it is especially important to harmonize their roles and responsibilities if any meaningful results are to be achieved, a situation South Africa currently faces. Clear coordination and communication within and between central government, devolved units, and other governance levels are critical for effective implementation of planned climate change actions. Various mechanisms of doing so are highlighted in the case studies, including oversight, financial and other capacity-building assistance, and regular progress reporting.

Mixed Climate Finance Strategies

The climate finance mobilization and management strategies are mixed. While expected sources of finance include public and private funds from both local and international sources, some countries opt to align climate-related actions to regular budgetary process and/or establish climate change funds along the lines of the UNFCCC's Adaptation Fund. Setting up and/or trading in the carbon market is still popular with many countries. Other proposals include improving the capacity of the public sector to efficiently and effectively absorb the expected climate finances and improving the general investment climate.

Concluding Remarks

Responding to the threat posed by climate change requires establishment of effective and efficient governance structures. For many developing countries, this process is already underway. The comparative analysis of the climate change legislative and institutional frameworks of the four developing and one developed country presented in this chapter reveals several emerging best practices which can constitute elements of a broad governance framework developing countries could reproduce or tailor to their domestic situations.

However, the results also raise broader issues that need closer attention and focus. One such concern is the need to incorporate and actively support the development of national climate change governance structures in discussions leading to the achievement of the outcomes of the Durban Platform for Enhanced Action. The "Durban Platform" is tasked with developing "a protocol, another legal instrument or a legal outcome" under the United Nations Convention on Climate Change (UNFCCC) applicable to all member countries by 2015. Such consideration would ensure synergy between national- and global-level efforts while appreciating the multilevel nature of climate change governance. The lack of an international enforcement body for UNFCCC-related proposed actions should reinforce the need to support national-level actions.

It is hard to tell whether the seeming enthusiasm by the developing countries sampled in this study to prepare national climate change legislations will spread significantly to other countries. However, success in their implementation will more likely inspire confidence in others to follow suit. Yet, such a successful implementation requires a range of other conditions to be met, resources or otherwise. There are many potential challenges which could derail the achievement of the intended outcomes of the so established climate change legal and institutional frameworks. Targeted capacity building in various areas is thus necessary. More important, however, is the need for sharing experiences by the different countries.

The apparent significance which developing countries attach to mitigation represents an important paradigm shift in the way mitigation is viewed. For a long time, mitigation and adaptation have been separated in both the academic and policy fields. The view that mitigation is a function of adaptation and that the two complement rather than antagonize each other, adopted by most of the developing countries analyzed in this study, is the closest to reality. What this reveals is that reducing emissions does not necessarily lead to a reduction in socioeconomic development. Such a revelation should inspire developed countries to cut their emissions not only as a way of slowing and hopefully reversing the current rate of global warming but also as a way of increasing welfare in those very countries and beyond. Genuine efforts at tackling climate change are linked to sustainable consumption and production. Dematerialization, decoupling, degrowth, and such sustainability buzzwords should not be mere rhetoric.

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Climate Compatible Physical Infrastructure in Coastal Bangladesh

Mustafa Saroar

Contents

Abstract

Concerns have been raised to make coastal physical infrastructure climate resilient for enhancing the resiliency of the coastal community. However, so far little has been done in this regard. This paper has threefold objectives. The first is to identify the nature of projects that have been implemented in the coastal areas that put higher emphasis on adaptive capacity maximization and ignored the issues of exposure minimization. Second is to unveil how donors' biases toward adaptive capacity building projects have undermined the climate compatible physical infrastructure development projects until recently.

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Third is to present the recent development as regards climate compatible physical infrastructure development with the support of the government as well as the donors.

This study is primarily based on review of data sources presented in the full chapter. It follows a meta-analysis technique for review of published studies on building resilient coastal communities in Bangladesh. Particularly studies and reports have focused on projects for adaptive capacity enhancements and exposure and sensitivity minimization through the establishment of physical measures such as coastal roads and highways, rural growth centers/markets, embankments, polders, sluice gates and cyclone/flood shelters, and afforestation program. While analyzing, the DPSIR (driving forces, pressure, state, impacts, responses) framework was used implicitly.

Although coastal infrastructures are in general vulnerable to both intensive risk and extensive risk posed by various hydrometeorological disasters, infrastructures are mostly vulnerable to cyclonic surges due to their higher 44 exposure. Although disrupted infrastructures seriously undermine the people's efforts toward building a resilient community, yet for decades, donors have neglected the issues of climate compatible infrastructure development; rather, they have pumped millions of dollars for community-wide adaptive capacity enhancement through NGOs. However, lately, it was realized that adaptive capacity enhancement alone can do little to build a resilient coastal community unless adequate attention is given for exposure and sensitivity minimization measures. It has appeared that investing in climate compatible infrastructure development could minimize the exposure and sensitivity of coastal people toward the threats of climatic disasters. Therefore, a new form of investment is underway, which will be discussed in the paper to a greater level of detail.

Keywords
Adaptive capacity • Climate compatible planning • Exposure and sensitivity • Coastal infrastructures • Bangladesh

The Science of Climate Change

Over the last two decades or so, there has been an enormous growth of literature concerning modification of weather, variability in climatic condition, and change in the patterns of climatic (hydrometeorological) disasters. The weather, which is the state of day-to-day atmospheric condition, is believed to become chaotic for quite a long time in many parts of the globe. This chaotic weather pattern has been turning to a regular event of climatic variation. Climatic variation is simply a deviation from normal climate. Climatic variation and weather extreme form the basis for climate change. Changes in pattern of precipitation, temperature, melting of snow and ice, and rising global sea level are all clear manifestation of global climate change (Alley et al. 2005; Nerem et al. 2006). Climate change is attributed to global warming. Global warming depends on the amount of carbon emission. Therefore, human contributions to future climate change largely depend on future emission of greenhouse gases. Then again future emission of carbon depends on the future state of the world (Cazenave and Nerem 2004; Nerem et al. 2006). Assuming various plausible socioeconomic development pathways (i.e., future state of the world) and using various models, scientists have developed various future climate change scenarios (Rajagopalan et al. 2002). Although the outcome of one model differs often markedly with the results of others due to the use of different set of assumptions, yet most models agree in some points. For example, most models acknowledged that temperature and precipitation have been changing and would continue to change.

From a multiplicity of models, this research heavily draws on the climate change scenarios of the IPCC. In fact, IPCC's emission scenarios (Leggett et al. 1992; IPCC 2001a) are extensively used to model climate change impacts (Hinkel 2005). The IPCC publishes every 5 years an assessment report of the global climate. Among its various reports, the second, third, and fourth assessment reports are the most widely referred. The fifth assessment report is due in 2013. Among various outputs of the models the change in temperature and precipitation which would contribute to the accelerated sea level rise and amplification of the devastating capacity of the hydrometeorological disasters have secured global attention (IPCC 2007).

Climate change due to global warming not only increases the air temperature but also increases sea surface temperature (SST) (Manabe and Stouffer 1980). With the increased sea surface temperature, the thermal expansion takes place in addition to melting of glacier and iceberg which leads to sea level rise (SLR). Thus, one of the major consequences of global warming and climate change is the SLR. Constant increase in sea surface temperature would cause thermal expansion which would cause SLR. Again due to the increase in global temperature, the process of melting of continental and polar ice sheets would be accelerated which would contribute to SLR. Both from tide gauge observation for the last 50 years and from the satellite altimetry measurements, a rising trend in sea level is confirmed (Nerem et al. 2006). Sea level rise may accelerate by a factor of 10 over present rates within the next century. It is estimated that global temperature rise due to the greenhouse effect may ultimately cause the sea level to rise as much as 3 m by the year 2100 (Castro-Ortiz 1994). However, the most widely used estimates are the two provided by UNEP (2002) and IPCC (2001a). According to UNEP, the humanity might experience an SLR of 1.5 m, and for the same period, IPCC projected a rise of about 1 m (88 cm). Therefore, acceleration in SLR has posed a formidable challenge for heavily populated coastal nations and small island nations (Adger et al. 2003). In fact, 180 million people would be affected from 22 coast-lying countries. Over 150,000 km^2 of land would be lost, including 62,000 km^2 of coastal wetland (Middleton 1999; Mimura 1999). Bangladesh would be one of the most severely affected countries in terms of number of population affected (Nicholls 1995; IPCC 2007; UNDP 2004).

Vulnerability of Coastal Bangladesh to Climate Change-Induced Events

Bangladesh is a tropical low-lying country. It has a population of nearly 150 million out of which more than 35 million live in the coastal fragile flood plain (Bangladesh Bureau of Statistics [BBS] 2011). Coastal area covers an estimated amount of 36,000 km^2 (Ali Khan et al. 2000). Some 700 km coastline is extended from east to west (Singh 2001). The country has 19 coastal districts in 3 distinct coastal zones. Among these districts, 12 districts have exposed coastline. There coastal zones are western, central, and eastern. In the southwestern part – known as the Ganges tidal plain – the topography is very low and flat. The largest mangrove forest – Sundarbans – is located here. The central region, being most active, experiences continuous processes of accretion and erosion. The eastern region, being covered by hilly areas, is more stable, and it has one of the longest beaches in the world (Figs. 1 and 2).

People in the coastal flood plains earn their livelihood primarily from agriculture, fishing, and similar natural resource-based activities. As the land price is low relative to other parts of the countries, mostly poor and marginalized people from various parts of the country prefer to settle here. Except some parts of the eastern zone, the entire coastal area is hardly 1 m above the mean sea level (MSL). Furthermore one-third of the country's landmass is under tidal excursions (Ali 1999, 2003). As the country receives enormous amount of ice-melted water from the Himalayan catchments and has poor discharge capacity, severe flooding is a regular phenomena (Schmuck 2000). About 20 % of the country experience regular flooding due to upstream water or heavy rainfall during monsoon. The coastal area is the one that experiences regular flooding, cyclone, storm surge, erosion, salinity intrusion, etc. (Islam et al. 1999). In the changing scenario of climate, the coastal area would experience one more disastrous event, i.e., accelerated SLR (Castro-Ortiz 1994; Nicholls et al. 1995; Ali 1999; Huq et al. 1998; Ali Khan et al. 2000; World Bank 2000; IPCC 2001b, 2007; Singh 2001; Cannon 2002; GOB 2006; Department of Environment [DOE] 2007) (Fig. 1).

Many of the above-cited studies projected a rise in sea level within the range of 0.50–1.5 m along Bangladesh coast [Bay of Bengal]. Although IPCC (2001a) indicated about 1 m rise by the end of this century, the United Nations Environmental Programmes [UNEP] (2002) projected a rise of 1.5 m. Although some experts opined that due to the subsidence effect of immature delta, the coastal area of Bangladesh might experience SLR of more than the above-cited figure, others ruled out such prediction. The latter group of experts believes that the coastal area of Bangladesh has been receiving enormous amount of silt from the Himalayan catchments which would help in lowering the level of SLR. Considering all the possibilities related to coastal dynamic of Bangladesh coast, Bangladesh government document accepted the US country study's lower projection of 30 cm and higher projection of 1 m [or 88 cm NAPA] (Government of Bangladesh [GOB] 2005). The National Program of Actions (NAPA) accepted that Bangladesh coast might experience 14, 32 and 88 cm rise by the years 2030, 2050, and 2100.

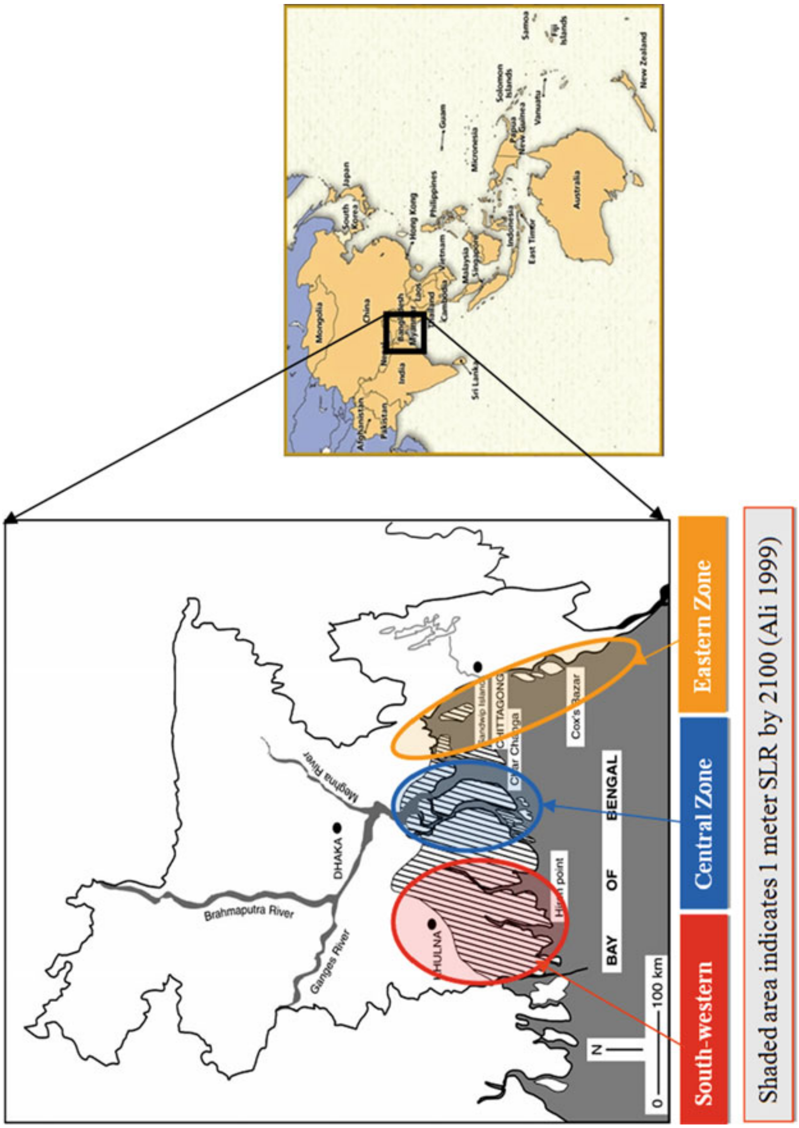

Fig. 1 Bangladesh in relation to countries in the Asia-pacific region (Source: Author)

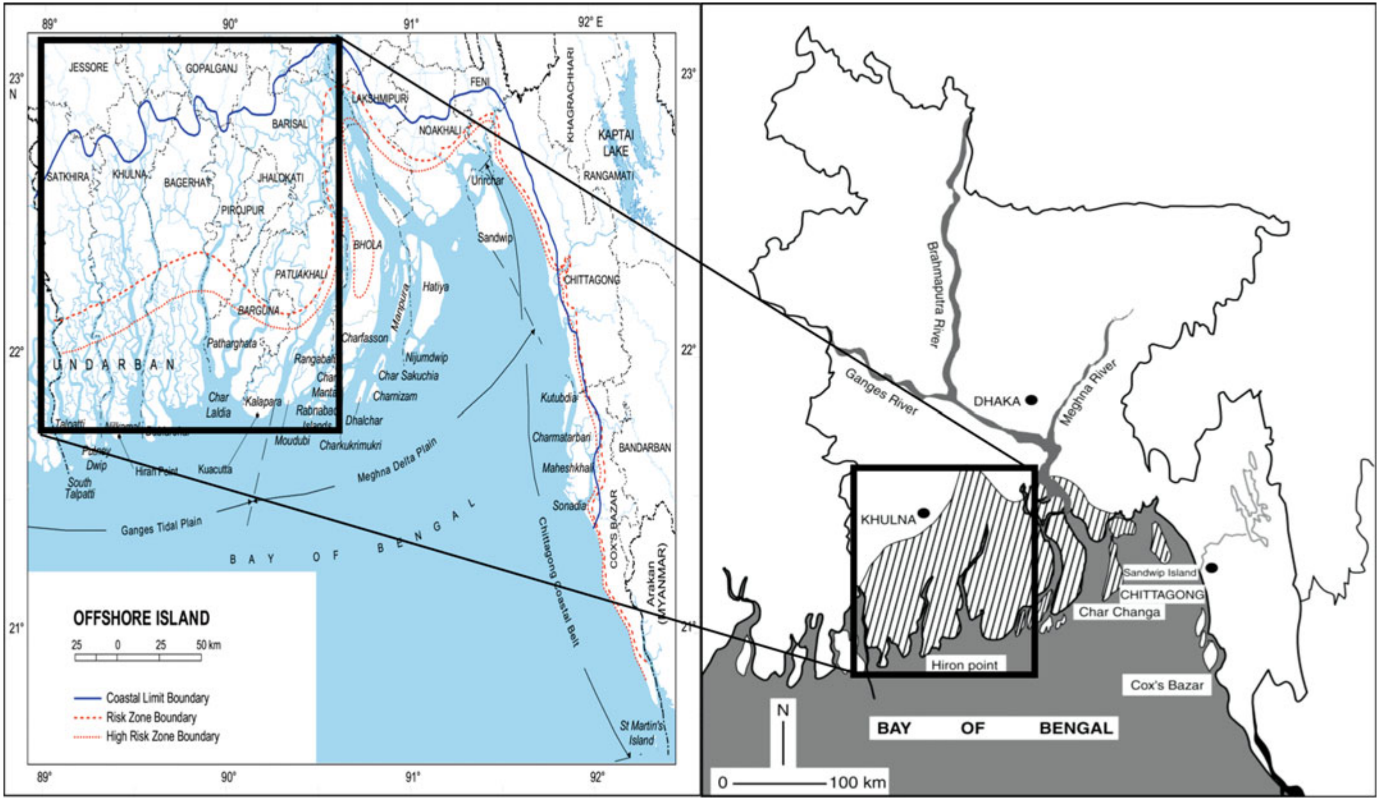

Fig. 2 South-west coastal Khulna region (inside rectangle) in relation to Bangladesh (Source: Author)

The increase of sea level along the Bangladesh coast is likely to enhance the risks of coastal flooding, salinity intrusion, storm surge, and even catastrophic cyclone (Ali Khan et al 2000; CARE 2003; Sing et al. 2001). Each of these would have various effects on coastal topography and morphology which would cause network of impacts on the lives and livelihood of coastal people. Some of the impacts are already visible.

Impacts of SLR and Its Associated Events in the Southwest Coast

The SLR would have a network of impacts on the low-lying parts of coastal areas because of the amplification of the devastating power of some of the already occurring events such as coastal flooding, salinity intrusion, cyclones, and storm surges. Because of tidal influence, some parts of the coastal area especially the southwest coast already have experienced the worst impacts of coastal inundation and saline water intrusion.

Assuming a population of 1995 and no adaptation (Nicholls 1995), Nicholls et al. (1995) estimated that a 1 m rise in sea level would inundate 24 million people and permanently displace as many as 15 million people. In such a case, the estimated amount of loss of land would be 25,000 km^2 (17.5 %). Same study argued that a 1 m rise in sea level and a 15 % increase in precipitation would inundate 71 million people because of massive flooding. Massive flooding may result from drainage congestion and water logging in the delta during high flow periods in the three major river systems in Bangladesh due to SLR-induced backwater flow. Although it is hard to forecast when such massive inundation would take place, it would have severe impacts on agriculture and forestry, food security, human health, transport and infrastructure, and settlement and housing. Therefore, Bangladesh is shown as rank 1 in terms of the number of population likely to be affected by climate change and SLR and its associated events (Nicholls 1995; Nicholls et al. 1995). If the future increase of population is considered, the number of affected people would be even more. An increase of 130 million people over the next 50 years in Bangladesh is projected, among which at least one-fifth would be from the coastal area (GOB 2009). However, another recent estimate by UNEP (2002) puts the number of displaced people at 17 million (15 % of the population) for a rise in sea level of 1.5 m along Bangladesh coast. Therefore, it is reasonable to assume that the projected SLR would generate considerable number of climate refugees

The effect of saline water intrusion in the estuaries and into the groundwater would be enhanced by combined effects of low river flow [during winter], SLR, and subsidence. The adverse effects of saline water intrusion would be significant on coastal agriculture (Ali and Chowdhury 1997; Faruque and Ali 2005; GOB 2006). Agriculture is the key livelihood avenue in the coastal area. Due to SLR perpetual intrusion of salinity in soil, subsoil water table and surface water bodies will have serious impacts on coastal agriculture (Huq, et al. 1998). The presently practiced rice varieties may not be able to withstand against increased salinity (Ahmed 2005). Therefore, food grain production may significantly reduce. IPCC's report (2007) under the title Climate change in Asia "too alarming to contemplate" projected that in Bangladesh, rice production may fall by 10 % and wheat by 30 % by 2050. Already about 830,000 million hectares of arable land is affected by varying degrees of soil salinity. More adverse impacts are projected for the coming decades, particularly for low-lying coastline and floodplain ecosystems (DOE 2007).

Coastal region that has very significant part in Bangladesh is about one-fourth of the country's population, with poor income groups forming about three-fourths of the coastal population. The coastal zone has diverse livelihood activities that are in danger to natural hazards and are also affected by man-made hazards.

Climate change can affect the productivity of coastal agriculture in a variety of ways:

- Changes in heat and rainfall affect the dynamics of ocean currents, the flow of rivers, and the area enclosed by wetlands. This will have effects on ecosystem structure and function and on the distribution and production of agricultural products.
- Increased incidence of extreme events such as floods, droughts, and storms affects the safety and efficiency of cultivation and increases damage and disruption to coastal services and infrastructure.
- Sea level rise, melting of glaciers at the headwaters of major rivers, and other large-scale environmental changes will have unpredictable effects on coastal and wetland environments and livelihoods.
- Complex links between climate change, farming, and other sectors have indirect effects being affected by changing water demands from agriculture, changing prices of and access to aquaculture feedstuffs, and diversion of government and international financial resources.

Another important dimension of SLR is salinity intrusion in mangrove forest Sundarbans. The IPCC Working Group II has indicated in its fourth assessment report that for a 1 m rise in sea level, the Sundarbans mangrove forest would probably be lost. Similar assertion is made by the Organization for Economic Cooperation and Development [OECD] in its study done by Agrawala and his colleagues (2003). Sundarbans mangrove forest not only provides ecological service; its resources provide livelihood opportunity for millions of people. If Sundarbans mangrove forest is affected, the livelihood avenues of dependent population would be severely affected. Furthermore, in the absence of Sundarbans mangrove, approximately 1,000 km^2 of cultivated land and sea product culturing area would be salt marsh. Likewise, SLR-induced salinity by reducing the amount of fresh water fishing area will cause reduction in fish production (Choudhury et al. 2005). Culture fisheries in the coastal area would be affected by intrusion of salt water into ponds, unless embankments are made around them. Shrimp farming in the coastal area is a lucrative business. Increase in salinity would probably jeopardize the shrimp farming as well (CARE 2003). For the last few decades, more and more attention is being given to sea fish and brackish water fisheries. The CC-SLR may arrest this trend.

The inundation of the coastal plains due to floods is common during monsoon (July to September). Because this time, it is often the case that the descending water from Himalayan catchments synchronize with heavy rainfalls and backwater flow from the bay due to tidal influence. As a consequence, floodwater continues to accumulate and bringing more areas under inundation. Backwater effects might aggravate the coastal flooding because of SLR (Ali 1999, 2003).

A direct consequence of SLR would be the intrusion of salinity with tide through the rivers and estuaries (Ericson 2006). According to an estimate of the Master Plan Organization (MPO), about 14,000 km^2 of coastal and offshore areas have saline soils and are susceptible to tidal flooding. A half meter rise of sea level would bring almost similar amount of coastal land under saline zone. Because due to SLR, the salinity front would be pushed further inland. The present interface between freshwater and saline water lies around 120–160 km inward from the shoreline. This would well be pushed further inward due to SLR (ADB 2000). For example, 5 ppt saline front would shift about 40 km inward due to SLR of 88 cm. A big chunk of the freshwater zone would disappear. Therefore, anticipated SLR would increase salinity in soil, subsoil water table, and surface water bodies (Ahmed and Alam 1998; Huq et al. 1998; Ahmed 2005).

Furthermore, SLR would cause shoreline retreat. It means the basin areas would increase along Bangladesh coast. Experts warned that this would allow the cyclone to remain longer in the water and acquire and release more latent heat. As a result, coastal areas may experience cyclones having more energy, intensity, and wind speed. Therefore, with the rise of sea level, the risk of cyclonic impact would be increased as well. For example, storm surge height might increase 13–46 % for SLR of 0.3 m and 1 m (for detail, see Ali 1999, 2003). Surge water that hits the coastline of Bangladesh would travel far inland. It means the risk zone (RZ) and a high-risk area (HRA) would shift inward. Since multipurpose cyclone and flood shelters are located in current risk zone and high-risk area [HRA], these shelters may be less effective as well because those would be standing in newly submerged areas.

From the forging discussion, it could be summarized that the projected SLR along the coastal areas of Bangladesh will be about 88 cm by the year 2100. If this comes true, a majority of the low-lying non-embanked coastal areas may be completely inundated. There will be increasing risk of coastal salinity (both soil and surface water). The mixing zone between fresh (sweet) water and saline water will also shift. Scarcity of saline-free drinking water will be even more pronounced. SLR will have compounding effects on coastal drainage and erosion. Land use suitability, particularly in relation to current agricultural practices, will change. Embanked coastal agricultural areas will be at higher risk of tidal surge and subsequent inundation with saline water. Therefore, the livelihood of coastal people would be severely affected in the coming decades due to SLR and its associated events.

Major Climatic Disasters and Impacted Infrastructures in Southwest Coast

Coastal districts, particularly those which have exposed coast such as Khulna, Bagerhat, Satkhira, Barguna, Patuakhali, Bhola, and Cox's Bazar, are particularly vulnerable to multiplicity of disasters including cyclones, storm surges, coastal inundation, salinity intrusion, etc. To protect the settlements in these areas from the 1960s onward, various infrastructures such as polders, levees, embankments, sluice gate, and cyclone and flood shelters have been constructed, the most notable of which are more than 2,500 cyclone shelters, 6,000 km embankment, 4,700 km drainage channel, and about 125 polders that have been constructed in addition to coastal greenbelt program. Although a significant portion of these exposure minimization infrastructures are in the southwest part of the coast, the sensitivity of this part of the coastal area is very high due to repetitive exposure to cyclonic and storm surges. Moreover, salinity intrusion and erosion causes damage to these infrastructures. Therefore, infrastructure failure is very common during the disastrous events which severely affect the life and livelihood f millions of coastal population. This southwest coastal area is affected by 2–3 cyclonic episodes each year. From 1950 about 50 cyclones hit this region. One devastating cyclone hits this area in every 5–10 years. Most recent cyclonic events that severely ravaged this area are Sidr and Aila. Although the death tolls were only few hundreds to few thousands, the damage of infrastructure and degradation of agricultural field were unprecedented. Almost 1,200 km protection embankment was either wholly or partially destroyed. Almost hundred thousand families were displaced from their settlements for few months to even 2 years due to these two devastating cyclones (GOB 2010a) (Table 1).

It is widely believed that due to change in climate, this kind of devastating cyclones would be even more apparent in the years to come. To minimize the impacts of such events, there is a growing need for anticipatory adaptation planning. Such anticipatory adaptation plan must include the exposure and sensitivity minimization measures and adaptive capacity enhancement measures (Brooks et al. 2005). Exposure and sensitivity could be minimized through building resilient infrastructure, and adaptive capacity could be enhanced through minimizing socio-economic vulnerability (Blaikie 1994). A starting point for building resilient infrastructure to minimize exposure and sensitivity could be detailed a inventory of the condition of all physical infrastructures such as polders, levees, dykes, embankments, roads, bridges, culverts, sluice gates, growth centers, schools, cyclone shelters, river ports and lending stations, hospitals, power stations, etc.

Adaptation to Climatic Disasters: Donors' Bias Toward Adaptive Capacity Building

A good number of initiatives have been taken so far, and some are ongoing as well to address the climate change impacts in various spheres of coastal life and livelihood. Such program covers emergency relief and rehabilitation to health and

Table 1 Major cyclones along coastal Bangladesh and respective surge heights

Cyclonic event	Season	Surge height (meter)
November 1876	Post-monsoon	3.0 ~ 10.0
May 1941	Pre-monsoon	4.0
May 1960	Pre-monsoon	3.2
October 1960 (first event)	Post-monsoon	5.1
October 1960 (second event)	Post-monsoon	6.6
May 1961 (first event)	Pre-monsoon	3.0
May 1961 (second event)	Pre-monsoon	6.0 ~ 8.0
May 1965	Pre-monsoon	7.6
December 1965	Post-monsoon/winter	8.8
October 1967	Post-monsoon	7.6
October 1967	Post-monsoon	7.6
October 1967	Post-monsoon	7.6
May 1970	Pre-monsoon	5.0
October 1970	Post-monsoon	4.7
November 1970	Post-monsoon	9.0
September 1971	Post-monsoon/winter	4.5
August 1974	Monsoon	6.7
November 1975	Post-monsoon	3.1
May 1985	Pre-monsoon	4.3
November 1988	Post-monsoon	4.4
April 1991	Pre-monsoon	4.0 ~ 8.0
May 2007	Pre-monsoon	6.0 ~ 12.0
November 2009	Post-monsoon	6.0 ~ 12.0

Source: GOB (2010a)

sanitation, food security, income generation to even infrastructure building to enhance the resiliency of the affected populations. In this respect, various donors such as European Community, USAID, DFID, and DSCC have been playing very instrumental role. Especially the European Union devotes huge sum of money for various projects under Climate Change Resilience Fund. Various local and international NGOs have been implementing a wide range of programs.

In fact, southwest coastal region being the most affected region in Bangladesh has so far got the highest international attention. A large sum of money already has been committed by various international development agencies to increase the resiliency of the region against climatic disasters and similar environmental stressors. Although for building a resilient community there is a need for package of programs which should include minimization of exposure and sensitivity and enhancement of adaptive capacity, analysis of recent trend shows that nearly all programs are targeted toward mainly adaptive capacity enhancement and, in some cases, sensitivity minimization of poor and marginalized coastal population (Table 3). It is probably because, first, the northern donors often prefer community-wide intervention for livelihood security; second, they intervene by engaging the local community with the help of NGOs. Therefore, exposure minimization – an important component of resilient community building – is always missing in their intervention. Therefore, although the poor and marginalized people enhance their adaptive capacity and minimize their sensitivity toward natural disasters by accumulating new skills and resources over time, these hard-earn gains are destroyed while they are exposed to devastating disastrous events next time. Therefore, greater need is felt by policy planners as well as the community as regards minimization of their exposure to those disastrous events. One way to do this is to invest in exposure minimization measures. Such investments include climate compatible physical infrastructures that relate to transport and physical communication, water supply and sanitation, health and education, marketing and trading establishment, construction of safe shelters, and protective embankments. Among these only some supports are extended by few northern donors (e.g., German Red Cross) for periodic maintenance of safe shelter and coastal embankments.

In Table 2, various programs/projects that have been implemented and also under implementations by such international agencies are presented in brief.

Climate Compatible Physical Infrastructure for Exposure Minimization: Current Status and Ways Forward

Especially after the massive strike of super cyclone Sidr in 2007 and Aila in 2009 which destroyed either fully or partially about 1,200 km protection embankment, the importance of exposure minimization measure for building a resilient coastal community came into the forefront (GOB 2009). Therefore, it was highly felt that coastal physical infrastructures, such as roads, bridges, culverts, embankments, dykes, polders, levees, sluice gates, cyclone shelters, urban drainage systems, schools, and marketplaces, need to be climate compatible. Although it is already late, still it is encouraging that policy makers, planners, government, and the donors have realized that only by enhancing adaptive capacity could a resilient coastal community not be built against the impacts of accelerated pace of climate change. In fact, scientific community warned that adaptation has its limit (Adger et al. 2009); enhanced adaptive capacity gives synergy to build resilient community if bundled with exposure and sensitivity minimization measures. In line with this new understanding, both the government and donors are coming forward to redesign their interventions.

Following the outcome of COP 15 (conference of parties), Bangladesh government expected that the bilateral donors would come up with funding support committed earlier for helping adaptation. However, when the United Kingdom (UK) announced that they would give their part of ODA (Official Development Assistance – earlier) with a new label for financing adaptation instead of establishing a new funding mechanism for helping adaptation, Bangladesh government refused to get that. Later in 2010, Bangladesh government in line with its Bangladesh Climate Change Strategy and Action Plan (BCCSAP) established initially a US$ 100 million fund from its own budget to finance adaptation. In the

Table 2 Review of major programs/projects which have been launched between 2007 and 2013 to enhance adaptive capacity and minimize sensitivity against climatic disasters in coastal Bangladesh

Donors and implementing agencies	Programs/projects name	Brief description	Strategies to reduce vulnerability
The Swiss Agency for Development and Cooperation (SDC) in partnership with local NGOs – Ashroy Foundation and Bangladesh Disaster Preparedness Center (BDPC)	Early Recovery, Cash for Livelihood (CfL) and Community Cyclone Shelter Program for the Cyclone Aila victims	The activities of CfL project were directed to increase the capacity of farmers, fishermen, small enterprise owners, and day laborers whose livelihoods were severely affected by cyclone “Aila” to overcome the loss of income in order to restart their economic activities through a cash contribution and to become independent from relief	Mainly for adaptive capacity enhancement and few measures for sensitivity minimization
		The main project objective was to reduce risk and vulnerability due to cyclones of communities living in high-risk areas in southern Bangladesh	
The UNDP Bangladesh was the lead agency. The project framework is based on broad partnership among government, UN agencies, local and international NGOs, interested donors, the private sector, and other stakeholders that play a critical role in disaster management	The Early Recovery Facility (ERF) project	The ERF project aims at generating sustainable and nationally owned processes for better and more effective post-crisis recovery, by linking post-disaster humanitarian rapid response with longer-term recovery actions that include measures for mitigation of future risks. The ultimate goal is to enable the local population affected by regular natural disasters to recover more timely and in a more sustainable way and ultimately to become more resilient to the regular setbacks caused by natural hazards	Mainly for adaptive capacity enhancement

(*continued*)

Table 2 (continued)

Donors and implementing agencies	Programs/projects name	Brief description	Strategies to reduce vulnerability
European Union	**Sundarbans Environmental and Livelihoods Security (SEALS) project**	The overall objective is to contribute to maintaining or improving ecosystem productivity and the environmental and social integrity of the north coastal lands of the Bay of Bengal	Mainly for sensitivity minimization and few measures for exposure minimization as well
		The purpose of the EU support is sustainable development of the Sundarbans Reserved Forest and the people who currently depend on its resources	
European Union	**Increasing Resilience and Reducing Risk of Coastal Communities to Climate Change and Natural Hazards in the Bay of Bengal**	The objective is to contribute toward poverty alleviation among poor communities in coastal areas of the Bay of Bengal, through reducing their risk to the impacts of hazards and climate change	Mainly for adaptive capacity enhancement
European Union	**Collective Action to Reduce Climate Disaster Risks and Enhancing Resilience of the Vulnerable Coastal Communities around the Sundarbans in Bangladesh and India**	The overall goal of the project is to reduce climatic disaster risks and enhance resilience of the coastal communities around the Sundarbans by building capacity of the vulnerable communities, local actors, and stakeholders through sustainable natural technologies	Mainly for adaptive capacity enhancement

European Union in cooperation with Relief International and local NGO – Uttran	**Social and Economic Security for Traditional Resource Users of the Sundarbans**	The overall objective is to reduce extreme poverty in the target areas through outreach to workers in the informal economy. The specific objectives are (i) to enable informal workers (traditional resource users) in the Sundarbans Impact Zone (SIZ) to attain decent work and break the cycle of extreme poverty and (ii) to empower them to identify, access, and advocate for social protection rights and services	Mainly for adaptive capacity enhancement
European Union in cooperation with Concern Universal and Dhaka Ahsania Mission	**Ensuring Water and Sanitation Facilities towards Disaster Risk Reduction**	The overall objective of the action is to promote people participation for reducing the morbidity and mortality caused by inadequate water and sanitation provisions in selected coastal disaster prone areas of Bangladesh	For sensitivity minimization and adaptive capacity enhancement
European Union in cooperation with CAFOD (UK), Caritas, and local NGOs – Prodipan and Dhaka Ahsania Mission	Improved Food and Livelihood Security in Bagerhat District, Bangladesh in the Context of Increased Disaster Risk and Climate Change (IFLS)	The overall objective of the action is to improve food and livelihoods security in Bagerhat District, Bangladesh, in the context of increased disaster risk and climate change	For adaptive capacity enhancement and sensitivity minimization
European Union in cooperation with BRAC	**Instrument for Stability – Restoring Socio-economic Stability and Strengthening Community Resilience in Areas Affected by Cyclone Aila**	The specific objective of this action is to support the rehabilitation of agriculture-based as well as nonagriculture-based livelihoods in severely cyclone Aila-affected districts of Bangladesh. In addition, the program would indirectly improve the food security situation of the most vulnerable population in the cyclone Aila-affected coastal areas	Mainly for adaptive capacity enhancement and few measures for sensitivity minimization

(*continued*)

Table 2 (continued)

Donors and implementing agencies	Programs/projects name	Brief description	Strategies to reduce vulnerability
European Union in cooperation with BRAC	**Instrument for Stability – Post-SIDR Livelihoods Rehabilitation**	The specific objective of this action was to support the rehabilitation of agriculture as well as nonagriculture-based livelihoods in severely cyclone Sidr-affected districts of Bangladesh. In addition, the program indirectly improved the food security situation of the most vulnerable population in the cyclone Sidr-affected coastal areas	Mainly for adaptive capacity enhancement and few measures for sensitivity minimization
BRAC	Bangladesh Agriculture & Food Security: Crop Intensification	To rehabilitate the victims of cyclone Sidr, BRAC introduced hybrid rice in winter (Boro/Rabi) season in the coastal area for the first time. The farmers cultivated this rice using tidal river water. Additionally, BRAC has implemented high yielding variety (HYV) and hybrid rice cultivation in pre-monsoon (Aus) and monsoon (Aman) seasons in traditional single-crop areas. BRAC introduced maize, sunflower, and other vegetables as new crops in areas with limited nonsaline water as part of the rehabilitation of Sidr victims	Mainly for adaptive capacity enhancement and few measures for sensitivity minimization
USAID in cooperation with Worldfish Center	Integrated Protected Area Co-management (IPAC)	The overall objective is to promote and institutionalize an integrated protected area (PA) comanagement system for sustainable natural resources management and biodiversity conservation that result in responsible, equitable economic growth and good environmental governance. USAID/Bangladesh expects IPAC to have widespread environmental, social and economic impacts	For sensitivity minimization and adaptive capacity enhancement

UK DFID in cooperation with local NGO – Uttran	Stimulation Household Improvements Resulting in Economic Empowerment (SHIREE): The Extreme Poverty Monitor and Information on Shiree's Change Monitoring System (CMS)	The aim of the project was to distribute *khas* (government wasteland) land among extreme poor landless people. The model involves government institutions (the Upazila, subdistrict administration; local government unit, Union Parishads) to effectively transfer *khas* land to the extreme poor. They maintain and share this database to other parties who would take program targeting this vulnerable group	For adaptive capacity enhancement and sensitivity minimization
UK DFID in cooperation with local NGO – Shushilan	SHIREE: Adapting Natural Resource Management to Climate Change and Increasing Salinity	The project is aimed to increase resources and sustain household incomes in ways that are resilient to climate change. Action program include activities that improve access to unused land and water bodies for the extreme poor. Furthermore, it provide need-based skills training and initial inputs and resources to test and develop agro-based microenterprises such as floating gardens, cultivation of rabi crops, mangrove nurseries, and crab fattening	Mainly for adaptive capacity enhancement and few measures for sensitivity minimization

Source: Author's review

next year, more US$ 100 million were added in that fund. Although this "Climate Change Trust Fund" is aimed to support programs/projects that fall broadly under six major themes, infrastructure development, comprehensive disaster management, adaptation knowledge management, capacity building, low carbon development, and food, nutrition, and health security, in reality lion share of the fund is allocated for climate compatible infrastructure development. For instance, in 2010–2011 financial years, about 75 % fund was allocated for projects that could play significant role in minimizing exposure and sensitivity to the impacts of climatic disasters. Therefore, most of this fund was allocated for climate compatible physical infrastructure development-related activities. There are complains about the process of selection of projects from this fund; Khulna region despite being one of most affected regions failed to get due attention. Among the 62 projects approved, Khulna region could benefit from less than 10 projects that address the issue of coastal resiliency. In Table 3, the name of the projects and the broad mechanism to enhance resiliency are presented in brief.

This poor number of projects from where southwest region could benefit in terms of increased resiliency against the climatic impacts gives a very clear signal that while this region is in most need, it is deprived of government fund. Then again most of these projects are implemented by various departments of Bangladesh government, the most notable of which are the Local Government Engineering Department, Water Development Board, and Forest Department. There is common concern about the quality of implementation work and capabilities of many of the organizations implementing these projects.

More recently both the government and donors realized that coastal rural infrastructure is directly vulnerable to the impacts of climate variability and change, as well as indirectly, through changes to the surrounding environment. To ensure its longevity and sustainability, any rural infrastructure investment, especially in coastal districts, must be resilient to climate change-associated extreme events. Inadequate attention to these impacts will increase the long-term costs of infrastructure investments and the likelihood that such investments fail to deliver the benefits for which they were intended (Thomalla et al. 2005). Therefore, the donors came up with a US$ 120 million new funding scheme called "Climate Resilient Fund" to support coastal resiliency. However, this funding scheme is too small when it is compared with the amount of funding required for climate change adaptation in Bangladesh. Revised NAPA prepared in 2009 identified 45 priority projects under six thematic areas which are roughly estimated to cost more than US$ 4 billion to implement. Bangladesh climate change strategies action program (GOB 2009) has roughly estimated the cost of about US$ 500 million (for years 1 and 2) to support programs for immediate actions such as strengthening disaster management, climate proofing of infrastructure, ensuring food and water security, research and knowledge management, capacity building and public awareness programs, and urgent investment in cyclone shelters. The total costs estimated in the BCCSAP for programs commencing in the first 5 years are at $5 billion. According to a recent study by the Institute of Water Modeling (IWM), Bangladesh needs at least $4.17 billion, only

Table 3 Projects funded from climate change trust fund that could enhance resiliency of Khulna region

Project name	Location/ impact area	Increase resiliency
Construction of Cyclone Resistant Houses at Char Area in Aila Affected District of Khulna	Khulna district	Through minimization of exposure
Construction of Cyclone Resistant Houses at Char Area in Aila Affected Districts of Chittagong, Barisal and Khulna	Khulna district	Through minimization of exposure
Dredging of Bolesshor river from Bagmara to Dopara (Via Khontaghata Platoon, kochua bazaar & Adajuri)	Pirojpur district	Through minimization of exposure and sensitivity
Protection and Repair of damage Sea-dyke and others infrastructure of the coastal polder no-63/1 A		
Re-excavation of Drainage Khal (natural canal) of Madaripur Beel Route Channel (MBR) of Gopalganj District	Madaripur/ Gopalganj district	Through minimization of exposure and sensitivity
Re-excavation of drainage Khal (natural canal) in Upazilla Kalkini, under Madaripur District	Madaripur district	Through minimization of exposure and sensitivity
Re-excavation of 24 (twenty four) drainage Khals (natural canal) in Upazila-Rajoir & Madaripur Sadar under Madaripur District	Madaripur district	Through minimization of exposure and sensitivity
Innovation of Sustainable Crop System for Drought Prone and Coastal/saline Area to Face Climate Change Impact	Nationwide	Through minimization of sensitivity and enhancement of adaptive capacity
Innovation of various mutenants Crop System for Drought Prone and Coastal/saline Area to Face Climate Change Impact	Nationwide	Through minimization of sensitivity and enhancement of adaptive capacity
Plantation of BWDB's Embankment in the Coastal Belt and its adjacent Char Areas	Greater Khulna region	Through minimization of exposure and sensitivity
Community Based Adaptation in the Ecologically Critical Areas Through Biodiversity Conservation and Social Protection	Greater Khulna region	Through minimization of exposure and sensitivity, and enhancement of adaptive capacity
Coastal afforestation to combat adverse impact of climate change	Greater Khulna region	Through minimization of exposure and sensitivity

for the construction of polders to save the lives of coastal people from sea level rise and storm surge. A joint assessment carried out by the GOB and Development Partners (DPs) after Cyclone Sidr in 2008 estimated that US$1.4 billion is required in the short term and US$ 4 billion for the long term (15 years) for adaptation and mitigation measures GOB (2010b).

Although this multidonors' fund is very small in amount as compared to the need, it is believed that this fund would help in arresting other funds as well for building coastal resiliency. Bangladesh government has participated in the Strategic Program for Climate Resilience (SPCR) prepared under the Pilot Program for Climate Resilience (PPCR). The PPCR is a program under the Strategic Climate Fund (SCF) within the Climate Investment Funds (CIF), to pilot and demonstrate ways to mainstream new approaches for integration of climate risk and resilience into development projects, policies and planning. The various project proposals under the Bangladesh's Strategic Program for Climate Resilience (SPCR), prepared under the Pilot Program for Climate Resilience (PPCR) package, strongly build on priorities identified by the Government of Bangladesh's executing agencies and are in line with the recommendations in the *Bangladesh Climate Change Strategy and Action Plan.*

With the support from ADB, World Bank, and IFC, several programs are under process. Most notable of which are:

- Investment Project 1: Promoting Climate Resilient Agriculture and Food Security
- Investment Project 2: Coastal Embankments Improvement and Afforestation
- Investment Project 3: Coastal Climate Resilient Water Supply, Sanitation, and Infrastructure Improvement
- Technical Assistance 1: Climate Change Capacity Building and Knowledge Management
- Technical Assistance 2: Feasibility Study for a Pilot Program of Climate Resilient Housing in the Coastal

Among the above programs/projects, the following two are directly related to building climate compatible infrastructure for building resilient coastal community.

Coastal Climate Resilient Water Supply, Sanitation, and Infrastructure Improvement Project

The Coastal Climate Resilient Water Supply, Sanitation, and Infrastructure Improvement project has components that relate to:

- Climate Resilient Water Supply, Sanitation, and Drainage Development: Develop water supply and drainage system in coastal districts which can provide safe drinking water and sanitation even with anticipated climate change impacts.
- Climate Resilient Infrastructure Improvement: Improve connectivity (small roads, bridges, culverts, etc.) within the coastal districts in a sustainable and climate-proof way to enhance the accessibility of the rural people in the coastal districts to social services, such as health and education and economic

opportunities, and to improve earnings for the rural poor including the poor women by widening the all-weather access to markets and livelihood activities.
- Climate Resilient Small-Scale Water Resources Improvement: Enhance agriculture productivity and sustainability and improve rural livelihoods in subproject areas through the sustainable small-scale water resources (SSWR) management, including flood management, drainage improvement, water conservation, and command area development.

In this respect, it should be noted that as a subproject of the above project, the *Coastal Climate Resilient Infrastructure Project* has been under operation from early 2013 with an estimated cost of US$30 million. Similarly another subproject *Coastal Towns Infrastructure Improvement Project* is in the final stage of approval by the donors. Funded by ADB, KfW, and IFAD, the Coastal Climate Resilient Infrastructure Project is launched in 12 coastal districts for the period of 2013–2018. These districts are Satkhira, Khulna, Bagerhat, Pirojpur, Barisal, Jhalokati, Bhola, Patuakhali, Barguna, Madaripur, Gopalganj, and Shariatpur. This project would deliver the following outputs as regards building climate compatible physical infrastructure.

Output 1: Improved Road Connectivity

The project will upgrade 537 km of rural roads, providing year-round connectivity between agricultural production areas and markets and to the other parts of the country. Road upgrading will involve improving existing roads to appropriate climate resilient standards and widening and rising of embankments, with suitable slope protection against erosion and wave action. The road crest level will be 800 millimeters (mm) above the normal annual flood level, with an extra height of 200 mm that will be added for the effective sea level rise to the standard 600 mm freeboard.

Output 2: Improved Market Services

The project will upgrade 274 rural markets with 15 % of space allocated to women. Each market will be connected either to an existing paved road or to one of those to be improved under the project. Infrastructure improvements include paved trading areas, sheds, water supply system, drainage facilities, sanitation facilities, and market offices. Some key elements within the markets, such as new market sheds, will be made climate resilient. These will be raised on concrete plinths to a level above the existing maximum normal monsoon high tide level plus the effective maximum sea level rise with an additional 250 mm freeboard.

Output 3: Enhanced Climate Change Adaptation Capacity

Upgraded Climate Disaster Shelters. The project will construct or extend 15 multipurpose cyclone shelters, improve 10 existing cyclone shelters, upgrade 15 km of cyclone shelter access tracks, and construct 5 *killas* (animal shelters). The designs will take into account climate change effects and strict compliance to relevant building codes with respect to wind loading and floor bearing capacities. Access roads/tracks will be upgraded to the equivalent of village road climate resilience standard.

Enhanced Knowledge Management. Knowledge management for climate change will be enhanced. A framework for expanding institutional learning and knowledge sharing will be developed. This will entail more effective knowledge capture and compilation, storage, and sharing on climate resilience principles for the design, construction, and maintenance of rural infrastructure. The project will strengthen the management information system (MIS) and geographic information system (GIS) of the Local Government Engineering Department (LGED), develop a special web-portal interface for learning and networking with other agencies, and support establishing a community of practice.

Enhanced Capacity. The capability of LGED staff and local government units will be strengthened to better prepare and manage climate resilient rural infrastructure.

Therefore, this project, while enhancing longevity and sustainability of infrastructure, will improve livelihoods in 12 rural coastal districts vulnerable to climate variability and change and have deficient mobility and accessibility. The project aims to provide climate resilience measures that deliver a degree of climate proofing commensurate with both the task that structures have to perform and the level of acceptable risk as well as being sensibly within available budgets. Each of the project components – roads; growth centers and markets; and cyclone shelters – has their specific tasks and levels of acceptable risk to the impacts of sea level rise (SLR), high wind, increasing temperature, and increasing likelihood of severe cyclone events. The underpinning thrust is ensuring that all structures are constructed within a strong framework of enforced appropriate specifications and an as-built quality audit. "Climate-proofing" measures include enhanced resilience to present climate effects plus forecast future climate change impacts.

Coastal Embankments Improvement and Afforestation Program

Similarly the Coastal Embankments Improvement and Afforestation program includes:

- Embankment Stabilization: Climate proofing (rehabilitate and/or raise the height/or realign) of existing polders/embankments to withstand the current and projected estimates of cyclone and tidal surges.
- Internal Polder Water Management: Rehabilitate, build, and/or improve water management-related structures (e.g., sluice gates, flushing inlets, regulators, drainage channels, etc.) within polders for improved drainage, reduced flooding and water logging, and improved agricultural and fish productivity.
- Afforestation: Raise coastal greenbelt along the embankments through afforestation/reforestation measures to counter tidal surges and strong winds and stabilize the embankment, coastal mapping, and research study on viable climate resilient tree species.

The objective of the proposed Coastal Embankments Improvement and Afforestation Project (CEIP) would be to support the first phase of the Government of

Bangladesh's long-range plans to (i) reconstruct and modernize the coastal embankments system to make it climate resilient; (ii) rehabilitate, build, or improve all water management-related structures within the embankments for improved drainage and reduced flooding and water logging and improve agriculture and fish productivity; and (iii) improve the coastal greenbelt along the embankments and reduce the impact of tidal surges and strong winds by implementing a systematic program of afforestation/reforestation measures. This CEIP project has the following components as regards climate compatible infrastructure planning for building a resilient coastal community.

Component 1: Rehabilitate or Build Climate Resilient Embankments to Protect Human Lives and Assets

This component will finance the optimal design, rehabilitation, and improvement of the embankment system in each polder identified for inclusion in phase I with due consideration to projected population density; economic activity of the area; the value of current assets to be protected and forecast projections for the next 20–25 years; return period and frequency of flooding, cyclones, and their probable direction; stability of current embankments; availability of local material for construction and maintenance; minimum and low-cost operations and maintenance; and impact of climate change and sea level rises.

Component 2: Rehabilitate or Build All Water Management-Related Structures Within Polders

This component will finance the design, rehabilitation, and improvement of all water management-related physical infrastructure and systems within the polders. This will include flushing inlets, sluice gates, regulators, drainage channels, etc., and will improve drainage, reduce flooding and water logging, and contribute to the improvement of agricultural and fish productivity and thereby improve food and income security and livelihoods.

Component 3: Coastal Plantation Along the Embankments

Most of the polders developed in Bangladesh do not have significant greenbelt or coastal plantation. It is only in the 1990s that coastal afforestation and plantation along the roadside and embankments became popular. Past climate-induced disasters have shown that mangrove greenbelts or coastal forests improve climate resilience. This component will finance afforestation along the embankments as appropriate. The greenbelts will strengthen the earthen polders and ensure their longevity. Afforestation will also increase general forest cover, reduce vulnerability against storm surge and cyclones, act as a carbon sink which will contribute to greenhouse gas mitigation, improve livelihoods, and provide habitat for wildlife.

The World Bank is currently funding an Emergency Cyclone Rehabilitation and Restoration Project (ECRRP). Under this project, a *Coastal Embankment Improvement Strategy and Phasing Plan* will be developed to modernize and improve the embankment system of about 125 polders in the entire coastal area. The strategy will also indicate a phased investment plan over a period of 10–15 years, as well as a detailed phase 1 investment plan to cover about 25–30 polders. This project is proposed for inclusion in the *Coastal Embankments Improvement and Afforestation Project*. Therefore, it is expected that in the years to come, a balance would be made among projects that target minimization of exposure and sensitivity and enhancement of adaptive capacity to truly build a resilient coastal community in southwest Bangladesh.

Conclusion

All these are targeted to increase the resiliency of the coastal community against the impacts of climate change on their natural resource-based livelihood. While the above programmed initiatives may have obvious advantages, there are challenges to initiate and implement these programs for building resilient infrastructure. First of all, the government machinery has limited staffing pattern and technical expertise to initiate and supervise design and implementation of such mega projects. Second, the donor's interest often shifts which might act as a hindrance to initiate and implement these kinds of programs. Finally, the participation of and coordination with development partners including the NGOs and civil society can make a difference in the implementations of these program.

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Conservation of Urban Biodiversity Under Climate Change: Climate-Smart Management for Chicago Green Spaces

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Abstract
Chicago Wilderness, a multistate alliance of more than 300 organizations dedicated to restoring biodiversity, is leading the effort to bridge the gap between climate science and biodiversity adaptation practices in urban natural areas and green spaces. In 2010, Chicago Wilderness completed the Climate Action Plan for Nature (CAPN), which describes potential climate change impacts within the 221,000 ha of protected areas in the region, and actions managers can take to help species and ecosystems adapt to climate change. The CAPN represents the first Climate Action Plan to address issues of biodiversity conservation in the Great Lakes region and is the only known example of place-based adaptation strategies for urban biodiversity. This chapter depicts the creation of the Chicago Wilderness Climate Action Initiative and the ensuing work to implement the CAPN, highlighting the challenges and importance of creating landscape level conservation approaches that integrate climate science information into best management practices. This collaborative effort can serve as a model for use in other urban centers.

Keywords
Biodiversity • Urban • Climate change • Adaptation strategies

Introduction

Recognizing the potential for changes in climate to disrupt their social and economic fabric, cities around the world are developing strategies for reducing greenhouse gas emissions, modifying programs to adapt to a warmer future, and engaging civil society in this effort. In addition to individual actions, cities have banded together to collectively advance local climate actions through the C40 Cities Climate Leadership Group, a network of 58 of the world's largest cities, and the World Mayors Council on Climate Change, with more than 80 members (Rosenzweig et al. 2010). In North America, more than 1,000 mayors signed the US Conference of Mayors Climate Protection Agreement (Hamin and Gurran 2009). Because urban areas are responsible for nearly three-quarters of global energy-related carbon emissions (Rosenzweig et al. 2010), the early emphasis of individual cities and these collaborations understandably was on reducing greenhouse emissions (Wheeler 2008). Only recently, as the inevitability of a rapidly changing climate has become apparent, have cities begun to focus on approaches to reduce risks in the face of climate change as being of equal importance (Bulkeley and Betsill 2013). However, urban adaptation efforts focus on protecting values like public health, livelihoods, and infrastructure, with little or no attention paid to protection of urban nature and the benefits nature provides to urban residents.

At the same time, cities and associated metropolitan areas are becoming increasingly important to global biodiversity conservation. Most cities have been founded in places that are biodiverse and functionally valuable to society, such as in floodplains, along coasts, on islands, or near wetlands. Today, urbanization continues to expand into these valuable habitats and into the hinterland where society most often placed its biological reserves (McDonald et al. 2008). Species previously outside city limits may need to migrate through urban areas as they adjust to a changing climate (Hellmann et al. 2010). Some metropolitan areas now contain important populations of rare species (e.g., Blanding's turtle and the prairie white-fringed orchid occur in the greater Chicago region), made more vulnerable to extirpation by their typically small population sizes and fragmented distribution patterns (McDonald 2013). Terrestrial natural areas in urban settings provide critical habitat for resident and migratory native species but tend to be small and isolated remnants of formerly widespread habitats that are increasingly vulnerable to loss and degradation from a host of urban-centric stressors (Kowarik 2011; Cook et al. 2013). Often termed "green" or "natural infrastructure" by urban planners, the ecological functions of these natural areas and other undeveloped or formerly developed spaces provide increasingly important, but highly threatened, benefits to biodiversity and human communities of metropolitan regions (Goddard et al. 2011; Hostetler et al. 2011; Kattwinkel et al. 2011). Likewise, freshwater biodiversity is threatened by both water withdrawal for urban consumption (McDonald et al. 2011) and the addition of pollutants from urban stormwater, industrial, and residential sources (Alberti 2005; Blanco et al. 2011). These biodiversity impacts are all projected to accelerate as global urbanization trends continue to increase (McDonald 2013).

Despite the regional and global importance of urban biodiversity, its conservation has rarely been addressed directly in urban climate change planning. As stated earlier, most of the focus of urban climate planning is on the reduction of greenhouse gases and on protecting public health and safety. If natural areas are addressed in a city-focused plan, it is typically in the context of green infrastructure, such as wetlands or plantings that help absorb stormwater, or as an adaptation strategy for reducing risks to people, for example, by helping to reduce the urban heat island effect (Enarsson 2011; Gill et al. 2007). Urban climate plans have not addressed the adaptation needs of open spaces, remnant natural areas, and populations of native species to help them to become resilient, persist, and continue to contribute to a biodiverse urban ecosystem and provide benefits to the human community.

A considerable gap therefore exists in most municipalities between conservation planning for nature and natural remnants and adaptation of urban environments for people. Hamin and Gurran (2009) point out that uncoordinated planning for biodiversity and ecosystem processes, on the one hand, and the built environment, on the other, can put the two in conflict. Turner and his coauthors go even further: "At present, climate change is seen as one problem for nature and another for people" (Turner et al. 2009, p. 278).

This chapter is a case study in metropolitan Chicago (population 9.5 million) where a conservation alliance is reconciling this dichotomy by taking a comprehensive regional approach to climate planning and action that incorporates the full range of assets, from social capital (human communities and the built environment) to natural capital (native species and ecosystems). The aim of describing this case study is to help advance such efforts in other cities around the world. In the sections that follow, efforts by the Chicago Wilderness alliance to develop climate change planning for urban nature and actions taken to develop and share adaptation strategies for natural areas in Chicago will be presented. It is the hope that lessons learned from the Chicago experience can be applied elsewhere.

Climate Change Planning for Urban Nature

Chicago Wilderness

In the early 1990s, conservation leaders in the Chicago metropolitan area recognized that a unified vision for biodiversity conservation was needed among their organizations in order to achieve sustained results (Ross 1997). The Chicago Wilderness alliance was launched in 1996 and has grown to include over 300 member organizations and corporations working toward common goals to restore nature and improve the quality of life for native biodiversity and human communities (Moskovits et al. 2004; Miller 2005). The Chicago Wilderness area includes parts of four states at the southern end of Lake Michigan (Fig. 1: Chicago Wilderness map; Caption: The Chicago Wilderness region), one of the Laurentian Great Lakes, and encompasses 221,000 ha of protected natural land that harbors rare natural habitats for resident and migratory species, including nearly 200 species threatened with extirpation either regionally or throughout their range (Brawn and Stotz 2001; Wang and Moskovits 2001; Miller 2005).

The Chicago Wilderness alliance accomplishes its work through four interrelated initiatives: (1) protect and restore nature and the ecological health of the region's land and waters; (2) advance a 567,000-ha natural infrastructure network that contributes to the quality of life of all residents; (3) provide places and programs for generations of families to connect with nature; and (4) develop and deploy actions through the alliance in the areas of climate change mitigation, adaptation, and education.

The Chicago Wilderness Climate Change Initiative began in 2007 with establishment of a Climate Change Task Force comprised of individuals from a wide range of organizations, including federal, state and local governments, NGOs, research institutions, zoos, museums, and an aquarium. Its first undertaking was to prepare the alliance for action by reviewing potential climate change impacts to regional biodiversity (Sullivan and Clark 2007; Chicago Wilderness 2008; Riddell 2009). Following this foundational review, the Task Force embarked on two phases that are described in the following sections: climate planning for urban nature, followed by the implementation of planned actions.

During the start-up period for the Chicago Wilderness climate initiative, the City of Chicago was well on its way toward preparing a Climate Action Plan. Released in 2008, it is the first such plan to be based on a thorough climate change impact assessment exploring the implications of a range of future scenarios on city life during the next century (Wuebbles et al. 2010). The City of Evanston, abutting Chicago to the north, also released a Climate Action Plan that year, and other

Fig. 1 Chicago Wilderness map. The Chicago Wilderness region

municipal and university campus plans were being developed in metro Chicago at the same time. As is typical, all these plans have an overwhelming emphasis on mitigation; collectively they propose significant actions that would lower greenhouse gas emissions from metropolitan Chicago. Actions to reduce risks related to climate change through adaptation were addressed only in the Chicago Climate Action Plan and only in relation to human communities, city services, and the built environment (Coffee et al. 2010). While the effect of climate change on ecosystems was part of the science assessment that informed the Chicago plan (Hellmann et al. 2010) and the city has passed ordinances to reduce impacts on natural resources, the Climate Action Plan did not include any actions to reduce risks to native species or ecosystems in its adaptation strategy (City of Chicago 2008).

Following the release of the Chicago Climate Action Plan in 2008, it became clear to both the Chicago Wilderness and the City of Chicago that complementary climate strategies were needed for the natural capital of metropolitan Chicago.

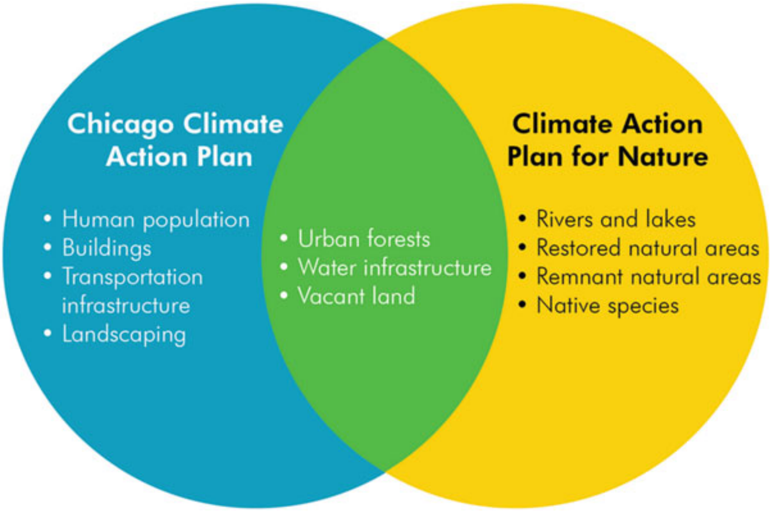

Fig. 2 Chicago Climate Action Plan and Climate Action Plan for Nature. The complementary relationship between the City of Chicago Climate Action Plan and Chicago Wilderness Climate Action Plan for Nature

Goals for such strategies would balance the municipal plans that emphasized mitigation and adaptation for the built environment by focusing on the persistence of native species and ecosystems, provisioning of services to citizens provided by natural infrastructure, as well as the "adaptation services" that open space provides in creating communities more resilient to climate change (Fig. 2: Chicago Climate Action Plan and Climate Action Plan for Nature; Caption: The complementary relationship between the City of Chicago Climate Action Plan and Chicago Wilderness Climate Action Plan for Nature). Chicago Wilderness also recognized that, done in isolation, the human response to climate change could compromise biodiversity, thereby accelerating climate change and reducing the planet's capacity to accommodate climate impacts (Turner et al. 2009). But there were no models for coupled human-nature climate planning in urban settings. Guidance for Climate Action Plans available at the time stressed reduction of greenhouse gas emissions, for example, with model plans for states (US Environmental Protection Agency 2012), cities (ICLEI no date), and even university campuses (Egan et al. 2008). Through a collaborative process, the Climate Change Task Force created a new template that became the Chicago Wilderness Climate Action Plan for Nature (Chicago Wilderness 2010).

Climate Action Plan for Nature

The Climate Action Plan for Nature was completed in 2010 with the primary goal of creating momentum across the diversity of organizations in the Chicago Wilderness alliance. Recognizing the rapidly evolving nature of climate change knowledge and practices, it was also meant to be the first iteration of planning for a dynamic climate action program for urban biodiversity in metropolitan Chicago. The plan includes three major components, engagement, mitigation, and adaptation. All three are tightly linked to the other Chicago Wilderness strategic initiatives mentioned above and mirror the three components of the Chicago Climate Action Plan.

Engagement – The primary engagement objective is for Chicago Wilderness members to become fluent in the vocabulary, concepts, and programs of a new era for urban conservation that includes climate change mitigation and, especially, adaptation. Ultimately, it is envisioned that well-informed members of the alliance will go on to influence decision-makers and their fellow citizens more broadly. Three sets of actions are outlined to achieve this. The first focuses on adaptation by establishing a Climate Clinic program within Chicago Wilderness (described in the next section). The second set of actions build the capacity of informal educators at the region's many environmental education centers to communicate the science and solutions of climate change to the public, especially young audiences and families. The third, more explicitly external, set of actions is to incorporate key climate messages into the general Chicago Wilderness public communications effort.

Adaptation – In this initial version of the Climate Action Plan for Nature, the emphasis is on catching up, that is, taking action to make current conservation strategies "climate informed." While most current protection and management activities in the Chicago region will help make nature more resilient to climate change to some degree, actions in this section of the CAPN focus on evaluating and modifying existing programs that were designed prior to knowledge of climate-induced challenges to enhance the ability of these practices to reduce climate-related risks and help resource managers avoid poor investments. The next sections of this chapter review progress toward meeting these adaptation goals since the 2010 release of the plan.

Mitigation – As a relatively small part of the plan, the CAPN mitigation actions focus on the role that protection and restoration of natural areas play in sequestering atmospheric carbon and the parallel risk of carbon release when habitats are destroyed. The primary mitigation objective is to create recognition of the need for land conservation in climate change decision-making. The plan also recognizes that protected areas play a dual role in climate programs by mitigating emissions as well as increasing the adaptive capacity for biodiversity and human communities.

Climate Change Update to Biodiversity Recovery Plan

The Chicago Wilderness Biodiversity Recovery Plan was collaboratively developed in the late 1990s to be the unifying driver of conservation strategies across the alliance. It was intentionally produced as a living plan that would continue to evolve as new information and new ideas arose. Not surprisingly, the focal biodiversity targets and critical threats that the plan identified 15 years ago were never evaluated with climate change impacts in mind. Since its formation in 2007, the role of the Climate Change Task Force has been to help the Chicago Wilderness alliance incorporate climate change into best management practices for restoring and managing natural communities. Much of what natural resource managers, and certainly restoration ecologists, are already doing to restore the health and functionality of natural areas "counts" as adaptation because it is making these areas more resilient to whatever changes may occur. Thus, the Task Force focused on what, if anything, is needed to be altered, included, or re-prioritized in the context of best management practices given the projected changes and likely impacts both to the region's biodiversity and to the threats species and natural systems were already facing (e.g., pollution, habitat degradation, fragmentation, etc.). This focus guided development of the CAPN, described above, and subsequent activities that include updating the Biodiversity Recovery Plan from a climate change perspective.

Over the past decade, it has become clear that climate change is one of the top threats facing Chicago's environment and its biodiversity (Wuebbles et al. 2010). Projections from climate models suggest that temperatures in the central USA, where Chicago lies, will rise from 2.1 to 2.7 °C by the mid-century compared with the recent past (Pryor and Scavia 2013). Beyond average temperature trends, summer heat waves in the city and extreme precipitation events during winter and spring are expected to increase (Hayhoe et al. 2010; Vavrus and Van Dorn 2010). These changes are predicted to affect human quality of life through public health, flooding, and water security impacts, as well as affecting aquatic and terrestrial biodiversity in myriad ways (Francl et al. 2010; Hellmann et al. 2010; Pryor and Scavia 2013). Many locations in the Chicago region will be climatically and ecologically unrecognizable by historic standards.

In the absence of actions that adapt protection and management practices, climate change has the potential to jeopardize many biodiversity conservation investments made in the Chicago Wilderness region during the past 30 years. Hence, the importance is given to adaptation in the CAPN and, the first priority in its implementation, to prepare a climate change update of the Biodiversity Recovery Plan. With this in mind, the Task Force initiated an in-depth effort to assess how a changing climate may impact the region's natural communities and compound existing threats to their ecological integrity (i.e., fragmentation, pollution, habitat degradation, and invasive species). This process involved translating downscaled climate change projections developed for the Chicago Climate Action Plan (Hayhoe and Wuebbles 2008) into an understanding of how a warmer, drier, and more extreme environment could affect regional biodiversity and, importantly, what management actions could be taken to reduce the impacts.

A great challenge to this endeavor is that understanding the vulnerability of species and systems to climate change is inherently interdisciplinary, requiring integration of information on climate science and modeling, theoretical knowledge of community, behavioral and restoration ecology, and on-the-ground knowledge of best management practices for natural resources in urban landscapes. As observed more broadly among resource managers in the Great Lakes region (Petersen et al. in press), managers within the Chicago Wilderness alliance were found to be often very aware of and interested in planning for climate change but felt they lacked the information and expertise needed to make updates in their management or restoration practices. This challenge of integrating available information to inform adaptation, however, is one Chicago Wilderness has been well

Fig. 3 Chicago Wilderness Climate Clinic. Resource managers and scientists discussing climate impacts to natural resources at the Indiana Dunes National Lakeshore

positioned to address because the alliance can tap into the collective knowledge of a vast intellectual network, ranging from research scientists in many academic fields to natural resource managers.

Between 2009 and 2012, the Task Force deployed Climate Clinics to marshal this knowledge network in beginning the process of ensuring resilient natural areas and open space in metropolitan Chicago. The Climate Clinic approach developed by The Nature Conservancy, whereby climate adaptation strategies are incorporated into ongoing conservation projects through an iterative, peer-learning process (Poiani et al. 2011), served as a model for these clinics. Beyond the important task of informing updates to the Biodiversity Recovery Plan, Climate Clinics also provide peer-to-peer interactions across several sectors of conservation science and practice and are useful for general capacity building of Chicago Wilderness members (Fig. 3: Chicago Wilderness Climate Clinic; Caption: Resource managers and scientists discussing climate impacts to natural resources at the Indiana Dunes National Lakeshore). Along with some individual interviews and topic-focused content reviews, the Task Force was able to solicit relevant expert opinion from over 100 regional conservation researchers and practitioners through two Climate Clinics. The clinics were full-day events that included a mixture of presentations and breakout group discussions, ending with an informal social setting and activity to promote networking and reinforce peer-to-peer learning. Often, simply presenting data and information is not sufficient to encourage dialog about how or whether concepts are meaningful and resonate with people, let alone persuade them to share their opinions based on personal observations of managing the landscape. The clinic format creates a comfortable and relaxed atmosphere, an important element in achieving critical idea sharing.

After two and half years of collaborative work, the Chicago Wilderness Executive Council approved the Biodiversity Recovery Plan Climate Change Update final document in the spring of 2012. This place-based climate change tool for the Chicago region now exists as a web-based resource (climate.chicagowilderness.org), where it continues to be updated as new information becomes available.

Place-Based Actions for Climate Adaptation

The CAPN created momentum for climate action across the Chicago Wilderness alliance, and the Biodiversity Recovery Plan Climate Change Update framed key risks to nature from climate change and linked those to possible adaptation strategies. From these plans, several projects naturally emerged to help the alliance take the next steps of connecting species and systems at risk in particular locations to actions that can be taken to help promote adaptation.

Accelerating the Pace of Adaptation: "Climate Considerations" for Urban Open Space

Building on the development of adaptation strategies for natural areas in the Chicago Wilderness region, the Chicago Department of Environment requested a partnership with The Field Museum, The Nature Conservancy, and University of Notre Dame to create a Climate Considerations Guidebook for natural areas and greens spaces in the urban landscape. The project was originally designed to develop an adaptation "checklist" that would assist City departments in implementing adaptation strategies. However, discussion with stakeholders quickly indicated that a universal checklist for all departments would not provide the kind of specific and useful information that was desired because sites have distinctly different goals and purposes (e.g., forest preserve conservation site versus a multiuse park district site), thus requiring different types of adaptation approaches. Instead, the concept of a guidebook that could help managers identify which of their management decisions may be sensitive to warmer, drier, and more extreme weather and provide resources to help them develop relevant adaptation strategies was the preferred path to follow.

The intended audience of the guidebook is mid-level managers of natural areas and green spaces in a highly urban setting. The first section of the guidebook is intended to convey the relevant information needed to begin the process of developing site-specific adaptation strategies. It begins with an overview of local climate change impacts and an explanation of why adaptation is important, followed by a seven step "workflow" that helps to walk the reader through the process of how to ask the "climate question" of urban natural area and green space projects. The next section poses probing questions in five categories (I. Getting started,

II. Safeguarding species and systems, III. Climate-informed land management decisions, IV. Operations and maintenance, and V. Rethinking goals) to help managers think through which management aspects may be affected by climate change. Following the questions in each category, specific tools and resources are suggested to help managers answer the questions and design their own approaches to reduce the vulnerability of a site to climate change. There are 63 tools and resources available in the guidebook, many of which connect managers to the place-based resources developed by the Chicago Wilderness, such as the Biodiversity Recovery Plan Climate Change Update and the Green Infrastructure Vision, but tools such as Climate Wizard and reports from other urban centers struggling with the same questions (e.g., Climate Change Adaptation Options for Toronto's Urban Forest) are included as well. The last section includes appendices intended to give additional background information (e.g., General adaptation principles, What does adaptation look like?) and an annotated list of all the tools and resources included in the guidebook.

A unique feature of this guidance is that it was developed with the intention of being deployed in an interactive format within the Collaboratory for Adaptation to Climate Change (www.adapt.nd.edu), in addition to being available as a stand-alone document. Funded by the US National Science Foundation and developed at the University of Notre Dame, the Collaboratory is a virtual community that is accessible to the public worldwide and can be used as a collaborative workspace and repository of documents and other information relevant to adaptation planning. The idea behind the Collaboratory is that by promoting more rapid sharing of information and ideas, networks can collectively speed up the pace and effectiveness of adaptation actions. The connection between the Collaboratory and adaptation efforts in the Chicago Wilderness again shows the importance of strong networks: the Collaboratory project leads were attracted to testing out novel technologies with the Chicago Wilderness alliance because of the strong history of collaboration, and several Collaboratory project team members have contributed to the Chicago Wilderness Climate Change Projects, as well as the City of Chicago Climate Action Plan.

Climate Clinics were again used as a mechanism to facilitate the collaborative effort between Chicago City departments and the Field Museum-Nature Conservancy-Notre Dame adaptation team. Participants in the clinics were named "Climate Adaptation Fellows," and their advice was gathered in regular meetings and through a private workgroup on the Collaboratory. Whereas the Biodiversity Recovery Plan Climate Change Update focused mainly on climate impacts to the region's larger natural areas (e.g., wetlands, woodlands, prairies, etc. in the Cook County forest preserves), this project was intended to help facilitate climate-ready decision-making by individuals working on smaller-scale urban natural areas and green spaces (street trees, park districts, boulevards, parkways, university campuses, etc.). This guidebook was crafted from a combination of stakeholder engagement and a literature survey, creating a tool that is both useful and informative.

The guidebook now lives in both a static and interactive format on the Collaboratory for Adaptation to Climate Change (available at, adapt.nd.edu/resources/1019/).

The interactive format, or “workflow,” walks users through the climate clinic process, with links to useful tools and resources. At every step, users are also prompted to contribute to discussions within a public workgroup and to provide feedback on the guidance that will inform updates (The workflow based on the guidance can be accessed at https://adapt.nd.edu/adaptationworkflows.). As of July, 2013, a simple search of “Chicago” in the Collaboratory yields ~50 hits to documents, events, or other resources used or generated in the adaptation planning process, most of which are connected to the Chicago-focused workspace. Over time, the Notre Dame team will study and implement improvements to the workspace and workflow, allowing lessons learned from Chicago to be shared with and benefit the broader adaptation community.

To test the utility of the guidebook, project leaders recruited four undergraduate interns to work with urban natural resource managers to evaluate the recommendations at five Chicago sites during the summer of 2013. Sites were selected based on interest from organizations that were involved in the development of the guidebook as well as a desire to represent a broad range of urban sites (e.g., park district sites with multiuse grounds, museum and university campuses, nature preserves, and natural area restoration sites). Each organization was required to designate one of their natural resource managers to be a mentor to the team of interns who collectively assessed each site. Mentors worked with interns to go through each section of the guidebook and answer as many of the questions as were relevant to a site and provided assistance in developing recommendations for incorporating adaptation into different aspects of their management and planning process. The mentors were also asked to provide feedback on how relevant and/or helpful the guidebook content was to them, including language and concepts used, extent of background information, questions posed, and resources provided. This feedback will be summarized for posting in the collaboratory and used to revise the guidebook in hopes of making it as useful as possible. Additional sites will continue to be piloted in 2014, and a comparative review of all the sites will be completed in order to gain an understanding of the different ways the guidebook can be used and the types of adaptation recommendations urban natural resource managers are developing.

Community Action Strategies

In order to empower and encourage Chicago communities to take action, social scientists from the Field Museum developed a set of Community Action Strategies designed to engage residents of the Chicago region in the goals of the CAPN in their own community through climate-friendly gardens and lawns, water conservation, monitoring, open space stewardship, and climate change education (Climate Action Plan for Nature, Community Action Strategies, www.climatechicago.fieldmuseum.org/sites/default/files/Climate-Action-Plan-for-Nature.pdf). To implement this set of strategies, the Museum led a coalition of over 40 partner organizations in Chicago neighborhoods to develop a bilingual Chicago Community Climate Action Toolkit (climatechicago.fieldmuseum.org). An interdisciplinary team from the Museum facilitated a research-to-action process for involving Chicago communities in implementing city (Chicago Climate Action Plan) and regional (Chicago

Wilderness Climate Action Plan for Nature) strategies for climate action, in ways that simultaneously advance their local agendas for social change. This work built upon previous ethnographic research the Museum conducted to understand socio-cultural viewpoints on climate change in Chicago's diverse neighborhoods (Hirsch et al. 2011). The toolkit comprises 60+ multimedia tools that communities can use to nurture local efforts tailored to their unique cultures that support city and regional climate action strategies.

Chicago Wilderness Green Infrastructure Vision

The Chicago Wilderness Climate Change Task Force was also moving forward during this time to integrate climate change impacts to biodiversity into another Chicago Wilderness effort, the Green Infrastructure Vision project (http://www.chicagowilderness.org/what-we-do/protecting-green-infrastructure/epdd-resources/biodiversity-and-natural-habitats/green-infrastructure-vision/). This project provides a visionary, regional-scale map of the Chicago Wilderness region that reflects both existing green infrastructure – forest preserve holdings, natural area sites, streams, wetlands, prairies, and woodlands – and opportunities for expansion, restoration, and increasing the connectivity of natural areas. The broader goal of this effort is to bring the Chicago Wilderness Biodiversity Recovery Plan to life in a more meaningful, visual, and accessible way for Chicago Wilderness members and outside audiences. In order to bring an explicit climate perspective to the project, the Task Force created a GIS layer to assess the pattern and magnitude of regional carbon storage, information that can be used to help quantify the climate-related co-benefit of keeping natural areas healthy and intact, and to assess where the biggest storage areas were located. This preliminary map, based on aboveground carbon storage associated with habitat types defined from 2006 National Land Cover Data, revealed the region stores more than 77 million tons of carbon, but only 5.4 % occurs on protected land. This illustrates the critical need to engage public and private landowners in conservation management issues.

In addition to assessing the role natural areas and green spaces play in storing carbon, the Task Force initiated a working group to evaluate how well the conceptual corridor models of the Green Infrastructure Vision work in reality for particular species, especially those that are climate-sensitive, at a particular site. As is the case with all Chicago Wilderness working groups, the individuals involved are self-selected and interested in contributing to the collaborative effort because the topic or project is specifically tied to either their own interest or that of their organization; in other words, their involvement helps to forward their own work as well as that of the Chicago Wilderness.

The Green Infrastructure Vision conceptual models for corridors, developed by The Conservation Fund (http://www.conservationfund.org/projects/refinement-of-the-chicago-wilderness-green-infrastructure-vision), were created for individual habitat types (woodlands, wetlands, prairies, etc.) using GIS Terrestrial Movement Analysis software (Norman 2012). This analysis tool uses the average dispersal distance for several habitat-specific species to create minimum movement pathways and corridors between landscape features [e.g., the average dispersal distance for the common muskrat (*Ondatra zibethicus*) and Blanding's turtle (*Emydoidea blandingii*) was used to create the wetland corridor] (CMAP 2012). The Task Force selected the federally endangered Hine's emerald dragonfly (*Somatochlora hineana*) to pilot this work and found corridors generally reflected the real biological conditions of the dragonfly at the site scale (Hasle unpublished data). Work is currently underway to test the model's validity for additional climate-sensitive species, with a goal of helping identify site-scale management implications.

Other related projects that are in progress include working with municipalities on climate-informed stormwater management and developing a regional urban forest adaptation guide. Overall, the Biodiversity Recovery Plan Climate Change Update resource has enabled Chicago Wilderness to effectively integrate both a climate and a biodiversity perspective into work being done at the site, neighborhood, community, and regional scale. These efforts are not only useful for the Chicago Wilderness region but can be scaled up to help inform similar work in other urban centers.

Lessons Learned

As stated earlier in this chapter, there were no models to follow that incorporated biodiversity conservation into urban climate change adaptation programs. Not surprisingly then, important lessons regarding helpful ways to frame the climate conversation and how to respond to challenges and barriers were learned along the way. Below are seven lessons learned, all arising from adaptation planning activities that were pursued in the Chicago region. These might benefit others contemplating similar efforts in their organizations or communities.

Frame the Climate Question in a Local Context

Mid-latitude regions, such as the Midwestern USA, are not yet experiencing the magnitude of temperature change occurring at high latitudes, or highly visible impacts like sea-level rise. While many climate change outreach efforts focus on threats to polar bears or coastal cities, framing this global issue in terms of how climate change is affecting (or expected to affect) species and habitats in the Chicago Wilderness region, as these are what local conservationists really care about was found to be very important. This was a particularly important way to connect with resource managers at Climate Clinics. Thus, Chicago Wilderness Climate Action efforts highlighted strong local impacts and worked with resource managers to connect these impacts to potentially vulnerable species and systems. For example, over the past several decades, the Great Lakes have seen dramatic changes in average ice cover, and the upper Great Lakes (Michigan, Huron, and Superior) have shown rapid increases in summer surface water temperatures, two changes that tend to act in a positive feedback as open water absorbs more heat, and warmer water takes longer to cool and freeze. Specifically, Lake Michigan has shown a 77 % decrease in ice cover (1973–2010; Wang et al. 2012), and summer surface water temperatures in southern Lake Michigan have increased by 1.4 °C, and the rate of increase is about 30 % higher than increases in air temperature during the same time period (1979–2006; Austin and Colman 2007). While it is not clear how these strong changes in local conditions will impact regional biodiversity, focusing on local changes provides both a sense of urgency and a place to start the dialog on how to respond.

There Are No "Experts"

There was a near universal reticence among conservation practitioners, especially resource managers, to participate in climate planning or adaptation clinics because they are not "climate change experts." Apparently there was an expectation that there were climate adaptation experts who already knew what to do and how to do it. These experts do not exist, however, because adapting to such rapid rates of climate change is a new challenge, and as of yet, there are few examples of adaptation implementation and learning from experience. Further, adaptation at the scale of a natural area requires integrating regional changes in climate drivers with information on local ecosystems, management practices, and constraints. Thus, it is always "local," and the most appropriate strategies will vary from site to site such that expertise from one location or habitat will not apply exactly in another. Finally, while many managers look to university partners to find "experts" on relevant topics, experts on adaptation theory do not fully understand the constraints and opportunities of applications in a particular place, as each place has a unique history, set of stakeholders, and priorities. This issue was addressed head-on in Climate Clinics and other engagement actions, telling people that advice about climate change abounds, but that no expert would be able to tell a manager what to do, because they did not know the specific system, decision context, and suite of (often competing) values to be considered. Partners were encouraged to develop their own expertise through helping us to write the Climate Considerations Guidebook and discussing ideas and adaptation options with their peers in the "Climate Fellows" meetings. It is not yet known if this strategy was effective, but there was a sense of increasing confidence among clinic participants that they have the knowledge and institutional capacity to implement adaptation and craft their own climate-informed conservation actions. The Collaboratory for Adaptation to Climate Change has a similar goal in the online universe – to remove institutional, temporal, and geographic barriers to information and knowledge sharing about climate change so that new expertise can grow in diverse places and at a pace that helps us keep up with the changing climate.

Uncertainty Is No Excuse for Inaction

Uncertainty about climate change has been used in political arenas to stall mitigation activities and that the same uncertainty can plague adaptation activities (Morton et al. 2011; Gifford 2011). Uncertainty about the future climate implies uncertainty about the specific stresses that adaptation actions should address.

In some cases, for example, the potential for increases or decreases in future Lake Michigan water levels (Gronewald et al. 2013) in the context of a coastal wetland restoration and adaptation actions designed for one scenario could represent a waste of resources under the alternate scenario. Sometimes these conflicts and trade-offs cannot be avoided, and choices will need to be made. But a better starting point is identifying robust strategies that are likely to be beneficial under a range of possible futures (Hallegatte 2009). For example, designing wetland restoration efforts with a landward buffer that permits inland shifts and with native species that can tolerate drying. The existence of these robust strategies is the best argument for taking adaptation action today and avoiding the uncertainty trap. It also is critical to recognize that inaction is a policy choice as well. Climate change presents a unique challenge because we cannot go back to the way things used to be, and leaving this as is could represent steady erosion in environmental quality and ecosystem services (Schwartz et al. 2009).

Personal Interaction Is Important and Stakeholder Engagement Is Critical

In an era where people increasingly interact via email, listservs, wikis, blogs, webinars, conference calls, and online social networks, the importance of in-person meetings and interactions should be recognized, particularly when a socializing component can be integrated into the experience. Sharing personal opinions and ideas about climate change impacts among professional colleagues, particularly if not everyone is well acquainted, can require a great deal of confidence and/or trust. Important qualitative information (e.g., how extremely low river levels due to changes in precipitation patterns resulted in increased predation on exposed mussel populations) tended to arise organically in an informal conversation. This information is often more forthcoming when personal relationships have been formed to create an atmosphere of trust and confidence for two-way dialog and iterative learning. It is critical to include stakeholder input from the onset so that useful products can be created. Natural resource managers are busy people; providing them with information that they have reason to consult/include is key if their participation is desired.

Adaptation Will Most Likely Occur in Places Where There Is a History of Collaboration

It is perhaps no accident that Chicago Wilderness is in the forefront of advancing ideas on how to design adaptation actions to benefit nature and people. The significant, long-term investment in support for collaboration across organizations to benefit nature is a major factor facilitating integration of information across disciplines and provides a network for sharing observations of climate impacts and critical support for creative problem solving. This bottom-up collaboration also includes the business sector, in addition to the government agencies, research institutions, and

NGOs that typically dominate climate-planning processes in the USA. More than 40 enterprises are members on the Chicago Wilderness Corporate Council, ranging in size from multinational corporations to local businesses. Harnessing strategic partnerships among organizations with differing talents and differing capacity for research and outreach has been found to be very effective. These organizations can come together to develop useful products for adaptation action. Our collaboration between a museum, a university, and a nongovernmental organization is one such example. Most major cities or regions will have each of these institutions.

Consider Multiple Audiences

An important lesson learned as part of the climate clinic process, and in developing the Climate Considerations Guidebook, was that adaptation needs to be defined and illustrated with examples in ways that are accessible to multiple audiences within the resource management sector. Outreach efforts targeted the practitioners, but a message heard repeatedly from this audience was that they needed clear information, and when possible, estimates of likely costs savings, so that these messages could be relayed to higher level managers and policy makers that have the decision-making authority to promote changes in key protocols or practices. Similarly, decisions to participate in collaborative management efforts that extend across ownership boundaries are often not within the control of individual site managers.

Ecosystem Services Have Their Limits, Especially in Urban Settings

A common approach in helping build support for investments in nature conservation under climate change is to highlight nature-based services that can help reduce climate-related risks to people. As we discussed this idea with resource managers, their response was that services, like retention or slowing of stormwater, could come with clear costs in this human-dominated landscape – fragile plants can be uprooted, and wetlands can be contaminated with road salt and other pollutants. Highlighting the service, an idea that we thought would help gain financial support for management and restoration could instead lead to a risk of additional stormwater being diverted to an ecological reserve, reducing its viability. As with other strategies for protecting the nature, all climate adaptation strategies need to be tested with those that know the system, stressors on that system, and the sociopolitical context for management.

Conclusion

Most greenhouse gases emanate from urban areas of the world, and it is critical that cities continue on the path of mitigating their impacts on the global climate by reducing emissions and creating more climatically sustainable energy policies and practices. In terms of recognizing that some level of climate change is inevitable in the coming century, some cities, such as Chicago, have begun implementing robust adaptation programs (Wheeler 2008; Stone et al. 2012). Cities, however, need to look beyond just their built environment to include natural capital in their adaptation efforts. Native species, remnant natural areas, and urban open space, along with a city's built infrastructure, must be included in climate adaptation programs to assure that cities reduce their vulnerability and increase their resilience to rapid climate change. Urban biodiversity is becoming increasingly important globally, and natural assets provide many ecological benefits and climate adaptation services that urban residents count on. There is no assurance that native species and ecosystem services will persist on their own in urbanized landscapes under fast-changing climate regimes.

This chapter has described a regional approach to climate change adaptation for urban biodiversity and ecosystem services that is transferrable to other metropolitan areas. This model complements the current strengths of cities in the climate change arena that primarily focus on mitigation and adaptation for the human community and the built environment. The approach is built around the power and success of the Chicago Wilderness alliance in metropolitan Chicago (Miller 2005), where a long-standing collaborative history was used to marshal a diverse range of resources and knowledge. Our model is best emulated in other areas with collaborative processes that can channel the knowledge of natural resource managers and research scientists into practical place-based adaptation solutions for urban nature.

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Development and Application of Good Practice Criteria for Evaluating Adaptation Measures

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Contents

Abstract

Decision-makers on different levels face an information deficit with regard to choosing promising adaptation measures. While the ever present concept of *good practice* may prove helpful in closing this gap, the term is often poorly defined. Therefore, this article attempts to substantiate the concept of *good practice* in climate change adaptation by developing a set of key criteria for evaluating adaptation measures. This potentially leads to sounder decision-making and a better transfer of experiences. By way of an extensive

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literature review, a variety of definitions and criteria for *good practice* in adaptation is revealed. Using predefined selection rules like *non-redundancy*, *applicability*, *comprehensibility*, *completeness*, and *measurability*, the identified criteria are condensed and then ranked by experts. This way, the article identifies six key evaluation criteria that should be considered when deciding whether an adaptation measure can be deemed *good practice* example or not. These are *effectiveness*, *robustness*, *sustainability*, *financial feasibility*, *positive side effects*, and *flexibility*. Subsequently, the set of criteria is illustrated by evaluating several *good practice* examples on the local level in Germany. Eventually, limits of the derived *good practice* criteria are discussed.

Keywords

Climate change • Adaptation • Good practice • Set of criteria • Decision support • Adaptation measure

Introduction

For many stakeholders involved, the development and implementation of climate change adaptation measures is a new challenge. It implies, inter alia, the necessity to react to already occurred climatic changes and to yet uncertain future changes (Bedsworth and Hanak 2010). In the face of this uncertainty, public and private stakeholders may find it difficult to develop suitable measures to adapt to climate change impacts or determine which of the potentially available measures are the most appropriate options (Hecht 2009).

Learning from good examples for climate change adaptation is a promising approach to support stakeholders with the planning and implementation of measures. Today, the concept of *good* or *best practice* is already used frequently in the communication of experience gained in the context of climate change adaptation (Land Use Consultants et al. 2006; Islington Government n.d.). However, at the same time, it has to be noted that the use of the concept of *good practice* is often vague and unspecific (Jennings 2007) requiring further research to specify the concept of *good practice* in the context of climate change adaptation (Foster et al. 2011).

For an effective and inspiring communication of a *good adaptation practice*, it seems necessary to substantiate the concept of *good practice*. A transparent approach to this lies in the development of a set of criteria, which can be applied to evaluating adaptation measures to determine whether respective actions constitute a good practice. Thus, the objective of this article is to identify *good practice* criteria for climate change adaptation measures in the context of industrialized countries, such as Germany. Relevant publications and websites are analyzed for that purpose. The research is based on preparatory work on the prioritization of adaptation measures carried out by the Federal Environment Agency (Tröltzsch et al. 2011, 2012; Kind et al. 2011). A consistent and compact set of criteria for *good practice* is derived on the basis of literature research and inputs from an expert survey.

The focus is not so much the analysis of individual examples of *good practice* as such, but rather the highlighting of general criteria of *good practice* that help identify measures as *good practice*. The particular measure and its nature or effects are more at the center of attention than the process of identifying or implementing the measures (as opposed to, e.g., the guiding principles for adaptation by Prutsch et al. 2010). Measures for the application of the set of criteria are primarily spatially and temporally defined activities that directly reduce risks of climate change and often have a more technical or structural nature. Informatory or regulatory measures are, however, not in the focus.

Pervasiveness and Challenges of the Good Practice Concept

Good practice usually describes a procedure that is considered exemplary and worthy of imitation because it has proven to be suitable and extremely successful in certain situations (UNESCAP 2012). The term *practice* refers to a measure, a strategy, a specific procedure, an approach, a methodology, a technique, a system, or a process (UNESCAP 2012). The *good practice concept* is an extenuated form of the *best practice concept* (Krems 2012). The identification and communication of *good* or *best practice* is carried out with the aim of using these initiatives as inspirational guidelines for the decision-making process in similar contexts. Due to the fact that it is often difficult or virtually impossible to determine a solution that is the only and best solution in terms of all objectives and all criteria, the *good practice* concept meets factual restrictions and demands better than the *best practice* concept. Therefore, the following remarks refer to *good practice*.

Although there are a variety of publications such as scientific articles or practical manuals and guidelines for adaptation measures, there are only few approaches for a systematization and evaluation of *good practice* in the context of adaptation measures (Abegg 2008; Laaser et al. 2009; de França Doria et al. 2009; Eriksen et al. 2011). However, in the field of climate change adaptation, it can be useful for decision-makers to review or develop envisaged activities with the help of concise criteria in order to ensure that the plans follow recognized standards *for good adaptation*. The development of a set of criteria to assess *good adaptation practice*s is meant to provide private and public stakeholders with some guidance for climate change adaptation. In the following, *set of criteria* refers to a group of defined criteria, which an adaptation activity should meet in order to be deemed *good practice*, i.e., exemplary and worthy of imitation.

This plan is, however, subject to four key challenges. First, the explicit consideration of climate change in different activities constitutes a very recent practice. For that reason, there is only little data available when it comes to defining successful adaptation and establishing why certain activities taken were particularly successful. Second, *good practice* criteria must ensure a balance between abstractness and concreteness in order to cover as many different areas of activity as possible and provide a sufficient guidance function for the planning or evaluation of measures. Third, experience with successful adaptation gained in other contexts, e.g., agriculture in a developing country, cannot be transferred unconditionally to the aforementioned scope of this article, which concentrates on industrialized countries. Fourth, the good practice criteria should be defined in a way that ensures that their implementation can be verified without an unreasonable effort. At the same time, however, the definitions must be sufficiently specific in order to avert unwarranted and objectively unfounded positive reviews of good practice.

In order to address these challenges, the identification of criteria within this research included manifold sources from industrialized countries. In addition, the subsequent choice of criteria was also based on interviews with experts from different subject areas to ensure a broad thematic validation of the selected criteria. Furthermore, the test application of the criteria toward the end of the article also discusses the risks that transferring *good practice* involves.

Methodology

In general, there are different potential approaches to identify a set of *good practice* criteria. One can roughly distinguish between three general approaches (Jennings 2007): the consideration of expert opinions, the analysis of theoretical literature, and the analysis of empirical evidence. In the first approach, a number of experts in the field of climate change adaptation are asked to name criteria that they think an adaptation measure has to fulfill to be considered a *good practice*. In the second approach, good practice criteria are derived from an analysis of relevant literature and the criteria that are mentioned in these publications. The last approach requires the analysis of successful adaptation measures for deducing common characteristics that were essential for their success.

To make use of the strengths of each of the approaches, the development of a set of *good practice* criteria in this article is based on the combination of an analysis of theoretical literature and the incorporation of judgments of experts from the field of climate change adaptation. The derived criteria set is then applied to a number of implemented measures to test for their applicability. This particular path has been adopted since there are only very few empirical studies concerning the success of adaptation measures.

The derivation of a set of practical criteria for the identification of *good practices* in climate change adaptation is based on seven consecutive steps. A large number of criteria that are deemed to define *good practice* are identified through a comprehensive literature search in relevant journals, monographs, and websites (1). Subsequently, these criteria are divided into thematic categories (2) and preselected according to predefined selection principles (3). The subsequent expert evaluation is used to prioritize and reduce the discussed criteria (4). An argumentative analysis then compiles a draft set of criteria (5). In order to test the applicability of the set, a number of adaptation measures will be evaluated tentatively considering the criteria developed (6). Following this test, the paper will discuss the strengths and weaknesses of the *good practice* approach in general and the set of criteria in particular (7).

Identified Categories and Criteria of Good Practice

As a basis for the identification of *good practice* criteria in the context of adaptation, 48 documents that touch on the characteristics of good adaptation in industrialized countries were identified with the help of a keyword search in a bibliographic database and evaluated subsequently. The majority of the identified sources are research papers or guidelines that have been funded by public bodies with a slight focus on publications stemming from Germany. Table 1 provides an overview of the 31 identified *good practice* criteria for the evaluation of adaptation measures or strategies. Because of duplications in terms of the mentioned criteria, only 21 of the 48 analyzed documents are specified in this table. For reasons of clarity, the table lists only that particular definition which the authors found to provide the most relevant explanation, regardless of the fact that some of the criteria have several descriptions. This overall view reflects the broad scope of the identified *good practice* criteria.

The criteria have been sorted thematically in Table 1. The identified criteria were divided into the following categories: *goals*, *goal achievement*, *costs and incentives*, *dealing with uncertainty*, *consideration of side effects and other objectives*, *consideration of stakeholders*, as well as the collective category *miscellaneous*. This method was chosen in order to structure the variety of criteria used in the literature and thus establish key issues, which can be evaluated subsequently by experts.

Table 1 does not only reflect the large range of potential criteria. It also indicates that these criteria or principles address different stakeholders: some authors refer to practitioners who deal with the implementation of measures, and others address policymakers who shape the strategic framework for adaptation measures. Furthermore, also the analyzed subject matter varies: to some extent, the analyses address rather comprehensive adaptation strategies, while others address more concrete measures. Linguistically, it can be noted that some sources adopt an evaluation perspective ("Was the adaptation strategy developed with the participation of all stakeholders concerned?") or provide practical guidelines ("Adaptation strategies should take concerned stakeholders into account"). Other sources, however, specify particular characteristics ("flexible") or effects of adaptation measures ("effective").

An evaluation of the 48 sources analyzed throughout the project shows that 25 sources (approximately 52 %) do not provide any information as to how the authors actually derived the criteria. In 16 (33 %) of the analyzed publications, the criteria are exclusively derived from literature searches and evaluations. Considering expert consultations (6 cases) or carrying out own investigations or resorting to own experiences with climate impacts and adaptation (2 cases) – however, only played a minor role – in total, this only amounts to approximately 15 % of the analyzed sources.

Overall, the analysis shows that in spite of several guidelines and brochures found throughout the research, practical experiences or expert interviews are only scarcely used for the purpose of establishing evaluation criteria for *good practice* in

Table 1 Evaluation criteria for good practice of climate change adaptation

Criterion	Description
GOALS	
Clear objectives	Develop and communicate verifiable goals for the adaptation project (UBA 2010)
Verifiable indicators	Qualitative or quantitative evaluation of the different adaptation options is available (Fünfgeld and Mc Evoy 2011)
GOAL ACHIEVEMENT	
Effectiveness	The degree of goal achievement or the likelihood that goals are achieved (UNECE 2009)
Feasibility	The measure is practical, i.e., the adaptation is not limited significantly by institutional, social, cultural, financial, or technological barriers (Smit and Pilifosova 2001)
Strategic importance	The course of action especially addresses seriously affected and endangered regions or areas of activity; the option has a reliable and long-term, goal-oriented effect (risk reduction); the option averts irreversible and dramatic damages (Vetter and Schauser 2013)
COSTS AND INCENTIVES	
Efficiency	Do the benefits of the adaptation's effects outweigh the costs and the expenditures of the measure (UBA 2010)?
Dynamic incentive	Does the measure entail a dynamic incentive toward a better adaptability or does it merely have a one-time effect (Tröltzsch et al. 2011)?
UNCERTAINTIES	
Flexibility	The measure can be modified or further developed; in case of a change of circumstances, the measure can be reversed (Vetter and Schauser 2013)
Dealing with uncertainties	The scope of potential future climate changes is taken into account (UBA 2010)
Reversibility	The measure can be reversed without causing unreasonable costs (definition following Prutsch et al. 2010)
No regret measures	The implementation of the measure is recommendable, irrespective of the climatic developments (De Bruin et al. 2009)
Robustness	The measure is effective not only in the context of one scenario but also under the different future climatic conditions (Hallegatte 2009)
Resilience	Measures that broaden the possibilities to prevent climate change and recover from its impacts (Land Use Consultants, Oxford Brookes University, CAG Consultants, Gardiner and Theobald 2006)
SIDE EFFECTS AND INTEGRATION	
Sustainability	Risks and measures are assessed by taking into account the interactions between economic capacity, social responsibility, and environmental protection; actions are aligned accordingly (following Bundesregierung 2011)
Positive side effects	The measure supports or does not conflict with goals of other federal strategies (sustainability, biodiversity, climate protection, etc.); it has positive side effects in different areas of action (Vetter and Schauser 2013)

(*continued*)

Table 1 (continued)

Criterion	Description
Win-win effects	Apart from their immediate effects, adaptation measures can entail further benefits also in other areas (Smit and Pilifosova 2001); win-win effects are often mentioned in the context of adaptation and climate protection measures (IFOK 2009)
Avoiding negative side effects	Adaptation measures can have unintentional negative effects on humans and the environment; these should be avoided by following sustainable adaptation strategies and measures (Eriksen et al. 2011)
Integration	If possible, measures should be integrated into an adaptation strategy and a multi-sectoral policy (Doswald and Osti 2011)
Mainstreaming	Integration of climate change adaptation into all relevant planning processes and development strategies (IFOK 2009)
PARTICIPATION	
Participation	Systematic involvement of all relevant stakeholders (IFOK 2009)
Cooperation	The capacity to establish good relations with other stakeholders; capacity to cooperate; capacity to deal with and resolve conflicts (Grothmann and Siebenhüner 2012)
Informative supervision	Develop an understanding and knowledge of climate changes, define climate risks and critical thresholds (UBA 2010)
Political and cultural acceptability	Social acceptance: to what extent do the affected social spheres accept the respective measure? Political acceptance: which degree of support can the measure expect at the political level? In that context, it has to be taken into consideration that the political acceptance is often closely linked to the social acceptance (Tröltzsch et al. 2012)
Equity	The effect (regarding costs and benefits) the adaptation activity has on various sectors, socioeconomic groups, and countries/regions and its temporal dimension should be taken into account (Feenstra et al. 1998)
MISCELLANEOUS	
Innovativeness	Climate adaptation measures are particularly effective when they are innovative – technologically as well as institutionally (Rodima-Taylor et al. 2012)
Priorities	Measures should address particularly important climate risks and chances (UKCIP 2005)
Long-term perspective	Continuity in terms of planning and implementation and regular goal verification (following IFOK 2009)
Evidence-based adaptation	Use of the most recent research results, data, and practical experience in order to guarantee well-founded and informed decisions (DEFRA 2010)
Transferability	The measure can be applied also to other regions (cp. Prutsch et al. 2010)
Subsidiarity	Required adaptation measures have to consider regional differences; in accordance with the principle of subsidiarity, they should be adopted and implemented at the most appropriate decision-making level. Strengthening the individual responsibility is an important guiding principle. Precautionary measures taken by other adaptation stakeholders ought to be promoted (Bundesregierung 2011)
Urgency	Urgency of the options refers to the need implementing the adaptation option immediately or whether it is possible to defer action to a later point in time (van Ierland et al. 2007, p. 258)

the area of adaptation. In many sources, the plausibility and thus the validity of the results is relatively small due to the lack of information on the methodology of deriving the criteria. Although the limited experience with climate change adaptation measures justifies such an approach to some extent, it does not explain why expert assessments are not increasingly taken into account. Against this background, expert opinions on the criteria of *good practice* seem to be of particular importance.

Applying Selection Principles

All of the seven established categories (*goals*, *goal achievement*, *costs and incentives*, *dealing with uncertainty*, *consideration of side effects and other objectives*, *consideration of stakeholders*, and the collective category *miscellaneous*) can be considered of relevance for the identification of *good practice* because each category covers several criteria mentioned a number of times in the literature. However, within the respective categories, there are considerable overlaps between some of the criteria.

Some of the 31 identified criteria are rather different in nature. Due to their variety and scope, they would hardly have a useful guiding effect when compiled as a set. Such an effect can only emerge if duplications are reduced, inapplicable criteria are sorted out, and definitions are specified. In order to identify particularly central criteria of *good practice*, selection principles will be used in the following to determine which criterion from one category can be deemed the most relevant. In three of seven cases, several criteria from the same category will be chosen (within the categories *dealing with uncertainty*, *consideration of side effects and further objectives*, and *miscellaneous*), since their respective content differs sufficiently from the other criteria's content (e.g., *flexibility* and *robustness*, *sustainability*, *positive side effects* and *integrated approach/integration* or *innovativeness*, and *evidence-based adaptation*). In the remaining four cases (the categories *goals*, *goal achievement*, *costs and incentives*, and *consideration of stakeholders*), it was possible to identify just one criterion that is representative of the other criteria of that respective category.

In line with Abegg (2008), selection criteria for a preselection are:

- *Applicability/feasibility* – the criterion can be applied to as many measures as possible.
- *Clarity/comprehensibility* – the criterion's intention is clear and distinct.
- *Assessability/measurability* – the quality and quantitative scope of the measure's effect can be verified.
- *Non-redundancy* – no criterion overlaps with other criteria so that duplications and overvaluations of individual aspects are avoided.
- *Completeness* – the set of criteria covers all important aspects; at the same time, it is concise and manageable.

The arguments for and against each of the criteria can be found in Table 2. To begin with, a large number of criteria were sorted out due to a violation of the requirement of non-redundancy in favor of other, superior, or broader criteria. In fact, 12 of the 20 criteria were sorted out because of a violation of this principle. The most important categories within which it was possible to integrate and thereby sort out several of the identified criteria are the following: *dealing with uncertainty* (4 criteria), *consideration of side effects and other objectives* (3 criteria), and *consideration of stakeholders* (3 criteria). In the abovementioned cases, the contents of the different criteria are so closely related (e.g., *dealing with uncertainties*, *reversibility*, *no regret measures*, and *resilience*) that it seemed reasonable to integrate them into the most comprehensive concept (which in this case was *flexibility*). The same applies to the category *consideration of side effects and other objectives* within which different criteria (*win-win effects*, *negative side effects*, *mainstreaming*) were summarized in the category either *positive side effects* or *sustainability*. The criteria *cooperation*, *informative supervision*, and *political and cultural acceptability* were summarized within the category *consideration of stakeholders* (covered by the criterion of *participation*). Furthermore, two criteria (*verifiable indicators and strategic importance*) were sorted out within the categories *goals* and *goal achievement*.

Additionally, several other criteria were sorted out due to a violation of the selection principle *applicability/feasibility*. Thus, five of the 20 criteria were sorted out because of a violation of this principle: within the category *miscellaneous*, the criteria *subsidiarity* and *urgency* were discarded. Furthermore, the criteria *feasibility*, *dynamic incentives*, and *equity* were sorted out from different categories. The remaining three criteria that were sorted out entailed violations of the following selection criteria: *assessability/measurability* (the criteria *priorities* and *transferability*) and *clarity/comprehensibility* (the criterion of *long-term perspective*).

The 31 identified criteria have already been assigned to seven categories (*goals*, *goal achievement*, *costs and incentives*, *dealing with uncertainties*, *consideration of side effects and other objectives*, *consideration of stakeholders*, *miscellaneous*). The number of identified criteria was reduced from 31 to 11 with the help of the selection criteria. Table 2 summarizes the selection process for the reduction of the identified criteria which were then presented to adaptation experts for further evaluation.

Results

A compact set of criteria is developed on the basis of the preselection of good practice criteria in the previous section and under consideration of experts from different scientific and practical fields. The expert opinions were determined with the help of questionnaires. For that purpose, eight climate change experts from German-speaking regions and with different professional backgrounds were asked to assess the preselection of eleven criteria in view of the following specifications:

Table 2 Overview of the selection process to select a reduced set of criteria

Criterion	Compatibility with selection principles	Conclusions
GOALS		
Clear objectives	Yes	Adoption for expert consultation
Verifiable indicators for goal achievement	No: (1) non-redundancy principle is not met; significant overlaps with the criterion "clear objectives"	Sort out in favor of the criterion "clear objectives" because that criterion has a better applicability
GOAL ACHIEVEMENT		
Effectiveness	Yes	Adoption for expert consultation
Feasibility	No: (1) applicability/feasibility (unnecessary in the context of evaluating already implemented measures); (2) clarity/comprehensibility (before the actual implementation, it is slightly unclear under which circumstances a measure can be held to be realizable); (3) non-redundancy (feasibility and transferability are closely connected)	Sort out because several selection criteria are not met
Strategic importance	No: (1) applicability/feasibility (the criterion focuses on a prioritization of measures rather than an identification of good practice)	Sort out because the selection criterion applicability/feasibility is not met
COSTS AND INCENTIVES		
Efficiency	Yes	Adoption for expert consultation
Dynamic incentive	No: (1) applicability/feasibility (suitable for comprehensive policy instruments but not for implementation measures)	Sort out in favor of the criterion "efficiency" because the latter is more exhaustive and comprehensive
UNCERTAINTIES		
Flexibility	Yes	Adoption for expert consultation
Dealing with uncertainties	No: (1) non-redundancy (content overlaps with the criteria "flexibility," "reversibility," "no regret measures," "robustness," and "resilience"); (2) clarity/comprehensibility (very general, procedural criterion)	Sort out in favor of the criterion "flexibility" because that criterion is more precise and descriptive
Reversibility	No: (1) non-redundancy (content overlaps significantly with the criteria "flexibility," "no regret measures," "robustness," and "resilience")	Sort out in favor of the criterion "flexibility" because that criterion is comprehensive and also covers reversibility
No regret measures	No: (1) non-redundancy (content overlaps significantly with the criteria "flexibility," "dealing with uncertainties," "positive side effects," and "robustness"); (2) applicability/feasibility (not a criterion but rather a type of measure)	Sort out in favor of the criteria "flexibility" and "positive side effects" because both can be held to constitute features of measures, whereas no regret refers to a number of measures

(*continued*)

Table 2 (continued)

Criterion	Compatibility with selection principles	Conclusions
Robustness	Yes	Adoption for expert consultation
Resilience	No: (1) clarity/comprehensibility or (2) non-redundancy (difficult to distinguish from the criterion "robustness"); (3) assessability/measurability (does not actually describe a feature of adaptation measures but rather a complex and specific effect)	Sort out in favor of the criterion "robustness"
SIDE EFFECTS AND INTEGRATION		
Sustainability	Yes, even though the measurability is questionable	Adoption for expert consultation
Positive side effects	Yes	Adoption for expert consultation
Win-win effects	No: (1) non-redundancy (content overlaps significantly with the criteria "positive side effects" and "robustness"); (2) applicability/feasibility (not a criterion but rather a type of measure)	Sort out in favor of the criterion "positive side effects"
Avoiding negative side effects	No: (1) non-redundancy (overlaps with the criteria "positive side effects" and "sustainability")	Sort out in favor of the criteria "sustainability" and "positive side effects"
Integration	Yes	Adoption for expert consultation
Mainstreaming	No: (1) non-redundancy; clarity/comprehensibility (overlaps significantly with the criterion "integration")	Sort out in favor of the criterion "integration"
PARTICIPATION		
Participation	Yes	Adoption for expert consultation
Cooperation	No: (1) non-redundancy (overlaps with the criterion "participation")	Sort out in favor of the criterion "participation"
Informative supervision	No: (1) applicability/feasibility (not relevant for every measure)	Sort out in favor of the criterion "participation"
Political and cultural acceptability	No: (1) non-redundancy (overlaps with the criterion "participation"); (2) applicability/feasibility ("good practice" should be evaluated regardless of the political will for implementation)	Sort out in favor of the criterion "participation"
Equity	No: (1) non-redundancy (overlaps with the criterion "participation")	Sort out in favor of the criterion "participation"
MISCELLANEOUS		
Innovativeness	Yes	Adoption for expert consultation

(*continued*)

Table 2 (continued)

Criterion	Compatibility with selection principles	Conclusions
Priorities	No: (1) assessability/measurability (much contextual knowledge is required in order to be able to assess the fulfillment of the criterion – which regions? which temporal scope?); (2) applicability/feasibility (more suitable for a prioritization of measures); (3) non-redundancy (closely linked to the criterion "evidence-based adaptation")	Sort out because the criterion focuses on a prioritization of measures rather than an identification of good practice
Long-term perspective	No: (1) clarity/comprehensibility (criterion is unclear)	Sort out due to the fact that it is unclear whether the criterion refers to (a) the longevity of a measure or (b) the long-term effects of climate change
Evidence-based adaptation	Yes	Adoption for expert consultation
Transferability	No: (1) assessability/measurability (much contextual knowledge is required in order to be able to assess the fulfillment of the criterion – applicable to whom? with what effort?); (2) clarity/comprehensibility	Sort out due to the fact that too much contextual knowledge regarding the circumstances to which the criterion should be transferred is required
Subsidiarity	No: (1) applicability/feasibility (the criterion is irrelevant for local/regional measures); (2) non-redundancy (participation)	Sort out because it is irrelevant for local/regional measures and is closely linked to participation
Urgency	No: (1) applicability/feasibility (the criterion focuses on a prioritization of measures rather than an identification of good practice); (2) assessability/measurability (much contextual knowledge is required in order to be able to assess the fulfillment of the criterion)	Sort out because the criterion focuses on a prioritization of measures rather than an identification of good practice

1 point = less important (*an adaptation measure can be deemed to be exemplary without meeting this criterion*), *2 points = important* (*meeting this criterion is important for the measure's exemplary nature*), *3 points = of crucial importance* (*a measure does not have an exemplary nature unless it meets this criterion*), *and further option* (*I do not understand this criterion*). In addition to evaluating the criteria, the experts were also asked to answer a few questions. The objective was to establish the appropriate scope of the set of criteria, optimize the comprehensibility of the respective criteria, and examine whether important criteria are missing and whether the content of individual criteria overlaps.

Table 3 Results of the expert consultations, sorted according to the arithmetic mean

Criterion	Evaluation			
	Average	Median	Mode	Standard deviation
Effectiveness	2.63	3	3	0.74
Robustness	2.50	3	3	0.76
Sustainability	2.50	2.5*	2.5*	0.53
Clear objectives	2.25	2.5*	3	0.89
Positive side effects	2.25	2	2	0.71
Efficiency	2.13	2	2	0.64
Participation	2.09	2	2	0.59
Flexibility	2.00	2	2	0.76
Integration	1.66	1.65**	1	0.72
Innovative-ness	1.54	1.5*	1.5*	0.58
Evidence-based adaptation	1.50	2	2	0.76

* These evaluations indicate decimal places because it was impossible to determine a distinct value if, for example, the number of times the ratings "2" and "3" were given is the same ("Most frequent rating" therefore "2.5").

** This rating came up because an expert extended the given scale and used decimal places himself/herself.

Table 3 shows how the experts rated the individual criteria. The criteria are ranked according to their average rating. The differently colored sections reflect the evaluations of the expert consultations. Because there were differing evaluations of some criteria, the table also indicates the standard deviation: the closer the figure is to the number 1, the stronger the expert assessments varied. However, if the figure is zero, there was a consensus among the experts. Additionally, the table indicates also the median and mode in order to meet the frequently rather high standard deviation. Especially where the results are particularly scattered, these parameters have a greater significance than the arithmetic mean.

Table 3 is divided into four areas differentiated by color: (1) Out of the eleven criteria the experts evaluated, the three criteria *marked in red* received the lowest ratings. The respective criteria are *integration*, *innovativeness*, and *evidence-based adaptation*. Their average rating is much lower than the medium answer category awarding two points. In all three cases, also the median and the mode were awarded with less than or exactly two points. (2) The four following categories *marked in orange* received an average, median, and mode close to two points. These criteria are *positive side effects*, *efficiency*, *participation*, and *flexibility*. (3) The criterion *clear objectives* that is *marked in yellow* approximates the leading group. While its average is in the upper middle range, its median and mode are already in the leading group. However, the standard deviation is relatively high. (4) The leading group is *marked in green*. It includes the criteria *effectiveness*, *robustness*, and *sustainability*. These criteria received positive ratings for the categories average, median, and mode.

In addition to the evaluation of the criteria, the results of the expert consultations also provided information on the designation and definition of some criteria. Against this background, some of the criteria were renamed and provided with amended definitions. For the further identification of the set of criteria, the following criteria were renamed:

- *Evidence-based adaptation = > climate knowledge-based adaptation*
- *Participation = > legitimacy*
- *Efficiency = > financial feasibility*

To ensure a transparent renaming, the criteria are referred to both with their previous and with their new denotation (e.g., "efficiency/financial feasibility").

In view of the definition of flexibility, it was noted by an expert that the definition's focus on costs is too narrow because transaction and opportunity costs should be taken into account, too (e.g., the period of time required to agree on the readjustment of a measure). The definition of sustainability was partially held to be linked too closely to the economic development. Therefore, the definition was broadened accordingly. The notion of efficiency/financial feasibility should also be accentuated differently because two elements of the original definition were repeatedly addressed: firstly, it was noted that it is usually not easy to determine the relationship between costs and benefits due to insufficient data, and secondly, those who implement a measure may find that the costs and benefits relation is often less relevant than the absolute costs and the related question of whether it is affordable at all. Therefore, a stronger focus on the overall financial viability and the benefits of financially comparable measures seems appropriate. In view of the criterion positive side effects, it was noted that its narrow focus neglects positive effects on the environment. Accordingly, the definition has been broadened. The definition of effectiveness was amended so as to focus less on the terminology "probability"; the aspect of entailed opportunities has been explicitly included in order to contribute to a broader understanding of the criterion. Furthermore, the experts were asked about what number of criteria for the set of criteria they assume to be manageable (Table 4).

The values given range between three and ten criteria; the two smallest and the two highest values appear only once. Only the numbers five to eight were mentioned more than once. The most frequently mentioned value is five. The average of

Table 4 Expert answers concerning the optimal number of criteria

Number of criteria	3	4	5	6	7	8	9	10
Number of times mentioned	1	1	5	3	4	2	1	1

all answers is 6.28, and the median that amounted to six criteria has a similar dimension. Based on this survey, six criteria seem like a reasonable size for the set. Due to the relatively unanimous below-average rating of the criteria in the red group (*integration*, *innovativeness*, and *evidence-based adaptation*), they were excluded from the final set of criteria immediately. Therefore, eight potential candidates for the final set of criteria remain.

Final Set of Criteria

Based on the expert survey, it was possible to define the criteria and the scope of the criteria set. The evaluation of each criterion enabled the rejection of three other criteria. Proceeding from here, a simple definition of the set of criteria based on the mean values of the evaluations does not seem sensible due to the relatively small number of consulted experts, the proximity of the evaluations, and the continued overlapping of contents. In order to ensure the objective of establishing a compact set of criteria, it is necessary to further reduce the number of criteria. In that regard, it is reasonable to consider the number of times the criteria were mentioned in the initial search and the standard deviations of the ratings.

Although the *clear objectives* criterion has received an above-average rating, it also has the highest standard deviation, i.e., the consulted experts held differing views in that regard. Furthermore, it is noteworthy that the *distinct (or clear) objectives* criterion was mentioned less often in the analyzed sources than the other eight criteria. For these two reasons, the *clear objectives* criterion seems the least relevant and will therefore not be included in the final set of criteria.

The experts gave the criterion *participation/legitimacy* an average rating. Also, the number of times it was mentioned in the sources was average. The category *consideration of stakeholders* covers a relatively large number of criteria, which suggests that it generally constitutes a much-discussed aspect with great importance for the model nature of measures. Feedback given within the course of the expert survey emphasized, however, that participation is not an end in itself but rather a means to achieve legitimacy. Provided that legitimacy is ensured by other means, participation is therefore not always crucial for the model character of a measure. Thus, in comparison with the other criteria, this criterion appears to be less significant because it can be assumed that the majority of actions have sufficient legitimacy. Accordingly, the criterion participation/legitimacy will not be included in the final set of criteria.

Therefore, the remaining six criteria are included in the set of criteria for good practice in the field of adaptation (Table 5).

Table 5 Final set of criteria for good practice in the field of adaptation

Criterion	Definition	Example
Effectiveness	The measure reduces the risks of climate change and contributes to the permanent use of opportunities.	A logistics warehouse in a region that is highly prone to floods is moved to a higher location in the context of a restructuring of the company.
Robustness	The measure has positive effects under different climate scenarios.	A chemical company that uses cooling water from a watercourse sets up an alternative cooling process, which does not require water and can replace the water cooling system if necessary. This measure can ensure a smooth operation also in high summer, regardless of how the summer water levels are affected by climate change.
Sustainability	The measure is well suited in terms of meeting all interests (economy, environment, society) and enables an environmentally and socially equitable development of society.	On the occasion of renewing the road surface, an administrative district chooses heat-resistant asphalt with vegetable oil in the bitumen content. Although it is slightly more expensive, its production and overall longevity is more environmentally friendly than conventional asphalt.
Financial feasibility	The adaptation measure is affordable for those who implement it, and alternative measures that cost the same do not yield higher benefits.	The installation of percolation basins in a development area as a precautionary measure to avert the effects of heavy precipitation was easily financed due to low investment costs and hardly any maintenance costs. Comparatively low-priced measures could not be identified.
Positive side effects	In addition to the adaptation to climate change, the measure has further positive effects on the environment, the society, or the implementing organization and the achievement of its objectives. These take effect even without occurring climatic changes.	When selecting new suppliers, a tool manufacturer decides to choose companies that are closer to the production location than before. The shorter delivery routes reduce the risk of damages to the supply chain occurring due to extreme events. The lower absolute fuel consumption also contributes to climate protection.
Flexibility	The measure can be modified with relatively low costs.	An organization that has been increasingly affected by extreme weather events in recent years insures itself against natural hazards. The selected insurance package can be terminated, reduced, or expanded annually.

Thus, the criteria in the set represent four of the seven categories of criteria – the categories *goals*, *consideration of stakeholders*, and *miscellaneous* are not taken into account. The categories *dealing with uncertainties* and *consideration of side effects and other objectives* are represented by two criteria. Although their respective contents contain some overlap, it seems reasonable in the light of the challenges of adapting to climate change to emphasize these two categories. At this stage, it still remains open how the set of criteria should be applied, i.e., whether a measure should, for example, meet all criteria or only a minimum number of criteria in order to be considered good practice. Furthermore, it was not investigated whether particular criteria have greater significance than others in terms of evaluating good practice for individual sectors or measures.

Application of Set of Criteria

In 2010, the German Federal Environment Agency established a database for measures to adapt to climate change in Germany. By now, this database has about 110 entries. It documents measures whose implementation phase has begun or been completed already. To select the best examples among the entries, the Federal Environment Agency started a competition in 2011. The selection of the award-worthy measures was based on the criteria *effectiveness and cost-benefit ratio*, *further benefits*, *participation and acceptance*, *feasibility*, *and transferability*. It had, however, not yet been systematically investigated whether this set of criteria suffices when it comes to identifying a *good practice* in climate change adaptation. Based on the expanded, consolidated set of criteria outlined above, the adaptation measures in the database were then evaluated to test the applicability of these criteria.

The specific conditions of the Federal Environment Agency’s database have to be taken into consideration. Adaptation measures included by external actors are the starting point for the evaluation. The entry of a measure follows a data entry form which has been provided by the Federal Environment Agency and addresses, for example, the following aspects: title, goal, and description of the measure, addressed climate impacts and fields of action, trade-offs and obstacles to implementation, participation, and financing.

The evaluation had to deal with the following practical challenges:

- The data entry form was not drafted in line with the subsequently identified set of criteria.
- It does not require that all entry fields are filled in.
- There are no requirements in terms of how detailed the description of the measure has to be, i.e., there is no guidance as to how to answer the individual questions of the form.
- The type of measures vary; often, there are conceptual preparatory works or strategic inventory analyses which in fact only prepare the actual implementation of the measure.

- Different stakeholders fill in the form.
- The self-portrayal by the measure's guarantor implicates that positive aspects are emphasized, while adverse effects may not be mentioned at all.

After screening the database entries, 25 measures were found to be suitable for an application of the criteria set. Furthermore, the screening found that 27 measures could be evaluated by the good practice criteria at least to some extent. In general, the application of the criteria shows that they are primarily suited for spatial and structural implementation measures, i.e., approaches for adapting so-called "gray" and "green" infrastructure. This includes, for example, flood polders and renaturation of water meadows for preventive flood protection, climate-adapted forest conversion, urban fresh air corridors, and adaptation measures in buildings. In contrast, the application of the criteria to regulatory, informational, communicative, and decision support measures is not useful.

While applying the criteria, the following aspects became apparent:

- The criteria *effectiveness*, *positive side effects*, and *flexibility* could overall be evaluated reliably.
- In many cases, it was not possible to apply *robustness* usefully; other cases only allowed for very general evaluations; however, in exceptional cases, the criterion was very relevant, for example, in the context of cooling through evaporation (cisterns) if potentially decreasing precipitation is not considered.
- Often, it was not possible to evaluate the *financial feasibility* because the total costs of the project were unclear or not communicated; in addition, it was difficult and time-consuming to determine the respective benefit and to compare the benefit with the benefit of other measures.
- The *sustainability* of several measures could not be portrayed in detail due to the fact that the term rather comprehensive and because its definition is relatively broad.
- Overlaps between *sustainability* and *positive side effects* were identified.

The main challenges when applying the criteria uncover the obvious methodological uncertainties. In view of several criteria, it is still unclear with which methodology they should be assessed. To this end, further research is required.

Considering all criteria, a *good practice* measure was identified when all criteria were rated positively. In some cases, however, a practice can also be held to be good although individual criteria were not met. *Robustness*, for example, is an important criterion when it comes to long-term, costly infrastructure decisions. However, if a measure is flexible and its implementation is cost-efficient, its implementation may remain useful even if the measure cannot meet all potentially possible climate developments.

In general, the set of criteria is suitable for the purpose of identifying good practice measures within the database of the Federal Environment Agency and to substantiate the preparation of the selection process. It contributes to the transparency of the evaluation process and covers important aspects that a suitable adaptation measure should fulfill. In order to provide an overall judgment on the basis of the individual evaluations of the criteria, a further consultation of experts considering the respective field of action seems appropriate to further consolidate the results.

Conclusion

In addition to suggesting a set of criteria, the derivation of *good practice* criteria entailed further conclusions. The research of criteria used in the literature in view of *good* adaptation has shown that the sources only very rarely relied on practical observations or opinions of other experts in order to justify the adopted criteria. So far, very limited experience with the effect of adaptation measures can be deemed to constitute a reason for the limited consideration of empirical data. Another reason can be seen in the fact that the majority of the criteria are very general in nature and are important for the selection and implementation of appropriate measures also in other topical areas (e.g., *efficiency*, *effectiveness*, and *participation*). Their general desirability then might not call for elaborate definitions and justification in the literature on climate change adaptation.

The challenge that arises when deriving a compact and easily applicable set of criteria is to justify which combination of the fewest number of criteria has the greatest relevance for the identification of *good practice*. The approach adopted here is based on a thematic grouping of the criteria followed by a selection of certain criteria on the basis of selection principles, which, for example, ruled out redundancies. Subsequently, experts evaluated the preselected criteria. In all three steps (grouping, preselection, and especially the evaluation by experts), the tension between the comprehensiveness of the respective definition and the comprehensibility of the criterion became apparent: the shorter and more abstract the description, the more difficult the evaluation within the preselection and the more frequent the different interpretations by the experts. It was not possible to dispel this tension in the final set of criteria.

The application of the set of criteria to adaptation measures from the database of the German Federal Environment Agency has shown that the problem with briefly formulated criteria can often not be resolved and the ratings thus forfeit their objectivity. In many cases, it was, for example, not possible to verify in detail the fulfillment of the rather abstract criterion "sustainability." This is due to both the lack of detailed information about the measure and the less concrete definition of the criterion itself. The problem with criteria which do not have a sufficiently precise formulation or for which there is no transparent methodology to examine their implementation entails the risk of window dressing, i.e., the whitewashing of suboptimal adaptation measures by decorating them with the criteria. If, however, one would reformulate the criteria in terms of maximum precision, the original purpose of this set of criteria – practical assessment of *good practice* – could no longer be met. Due to the existing uncertainties, the set of criteria cannot provide final judgments in terms of the evaluation of good adaptation practice. It can, however, prepare the according decisions through the structure of the criteria. The set of criteria achieves this with its special focus on the two issues that play a significant role in the context of adaptation: dealing with uncertainties and consideration of side effects.

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Gender and Health Adaptation Measures to Climate Change in the Pacific: A Case Study of Papua New Guinea

Sabrina Regmi

Contents

Abstract

This chapter examines the relationship of climate change, health, and gender in the Pacific region; identifies gaps in research, capacity, and support; and proposes a framework illustrating the practical adaptation measures to be applied in strengthening the Papua New Guinea's (PNG) public health sector capacity and policy. Using literature review as the research method, the study found that although other countries in the pacific are mostly affected by the climate change impacts, PNG remains highly affected by the climate-induced health impacts. Hence, a case study on Papua New Guinea was prepared. The chapter provides a practical understanding and knowledge on emerging health threats, gender issues, and adaptation measures to strengthen the Pacific and PNG's public health system. The framework presented in this chapter could be highly beneficial not only for PNG but also for the whole Pacific region.

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Climate change • Health • Gender • Adaptation measures • Pacific • PNG

Introduction

Although there has been a historical trend of health impacts of climate change at local level, the global attention of health issue in the climate change debate is a late comer in parallel with gender issue. It started getting attention during the 1990s when the World Health Organization (WHO) and the Intergovernmental Panel on Climate Change (IPCC) raised importance of health problems along with gender as the alarming issue in climate change regime (WHO 1990; IPCC 1990).

Both IPCC and WHO reports forecast that extreme climate events as well as changes in weather patterns and climate variability such as temperature and precipitation are expected to bring changes in the environment which may disrupt the socioeconomic lives of people, mostly living in the rural areas. Potential health impacts are expected to occur from the following climate change indicators: increases in extreme events, increases in temperature, decreases in rainfall, and increases in sea level (IPCC 2007). These indicators cause the disruption of the physical and ecological environment and the biological system which eventually threatens the socioeconomic system that functions within the physical, ecological, and biological system. Environmental threats such as contamination of potable water due to flooding leads to health risks such as those transmitted from infectious disease. Similarly, decrease in rainfall results in water shortage (rainwater) that leads to drought and shortage of potable water which consequently leads to food insecurity and poor sanitation and consequently affects nutrition and hygiene (Costello et al. 2009). Similarly, health-related problems may also arise from destruction of socioeconomic systems such as infrastructure that may consist of water sources, sanitation, and drainage and public health center itself (Ebi et al. 2008). Post-disaster impacts such as mental health conditions (depression and anxiety) may occur due to disruption of the social system, loss of livelihood, displacement, and migration (Costello et al. 2009).

Changes in climatic conditions affect directly (through changing extreme weather patterns) and indirectly (through changes in air, water, food quality, and infectious disease transmission and reproduction). Most of the studies in the developing countries show projected impacts that show similar health concerns arising from various climatic factors (for details see, McMichael 1997; Kovats et al. 2006; WHO 2011).

So far sectors such as water and agriculture have been cited in many global and national reports as well as studies as the important sectors for adaptation to climate change impacts, and thus, the measures are recommended and designed from the perspective of these sectors (Lovell 2011; ADB 2011). In the Pacific region, health sector itself has not been included fully and response from the sector has been few (Lovell 2011). Public health planners and policy makers have also been excluded from discussions, debate, and policy making which often takes place within the climate, environment, and agricultural sector, among the professionals in these fields (Lovell 2011).

The study aims to review the past assessments, adaptation measures, and role of public health sector and their response. The study aims to fill this gap in the Pacific regional context and particularly in Papua New Guinea (PNG). The purpose of this chapter is to examine the relationship of climate change, health, and gender in the Pacific region; identify gaps in research, capacity, and support; and propose a framework illustrating the practical adaptation measures to be applied in strengthening the Papua New Guinea's (PNG) public health sector capacity and policy.

Theoretical and Empirical Perspective

There are more predictions of the climate change impacts on health as compared to observed ones. The IPCC assessment (IPCC 2007) provides the evidence of these predictions to be based on scientific means, and most of these are from the developed countries (such as Europe). Hence, health impacts also have been mostly observed in developed countries, such as the extreme heat-related deaths in Europe, changes in vector-borne disease also in Europe, and increases in seasonal production of allergenic pollen in Northern Hemisphere's high and mid-latitudes (IPCC 2007).

Most of the studies looking into the climate change-induced health impacts have projected the likeliness of future health risks, and there are very less contributions to the knowledge on current vulnerability, risks, effects, and adaptation. Efforts have been put toward modeling of future health impacts of weather events such as heat waves, excessive rainfall, patterns of diseases, and food production (Kovats et al. 2005; McMichael et al. 2005, 2008; Lieshout et al. 2004) based on scientific indicators. Very few studies have looked into the risks from the social perspective such as health and gender. For instance, a quantitative study by Kolstad and Johanssan (2011) at a global level computed the projections of future climate change-induced increase in diarrhea which shows that it would increase up to 4 °C over land in the tropics and subtropics by the end of this century.

Nonetheless, IPCC (2001, 2007), WHO (2003, 2010), and IIED (2011) reports state the most vulnerable will be the small island states (located mostly in the Pacific region) and coastal areas in the developing world. Climate change can be a real threat to health of the population living in the Pacific, and their chances of survival and capacity to adapt to could be at stake, as larger population in this region depend on the sea/coastal, agricultural, and fisheries resources for their livelihood that are often damaged by the changes in climate variables and disasters. Hence, they face higher risk of suffering from different kinds of health-related problems such as malnutrition. For example, costal reefs are highly vulnerable to climate change impacts such as sea-level rise. Moreover, reefs are considered the major source of food and the main source of protein in Pacific people's food intake, with over 100 k of fish consumed per person per year (WHO 2003).

Climate change-related health risk from a wide range of diseases and injuries can be easily quantified (e.g., deaths due to storms) but sometimes it is difficult to determine through quantification (the health consequences of food insecurity). Studies show that whether the potential for climate-related disease is translated into actual occurrence of death and illness depends on both how quickly and how successfully humans adapt to new conditions.

In the Pacific context, a study by Patz (2002) using time series analysis of historic cholera in 1893 examined the effect of stationary interannual variability associated with climate change which showed that warming trends over the last century are affecting human disease. Similarly, Singh et al. (2001) studied the impacts in the 18 regions in the Pacific which show some observed (evidence based) outcomes through time series analysis. Based on data between 1970 and 1995, the study shows positive association of dengue with the Southern Oscillation Index (SOI), denoting El Niño condition. It further shows positive association of diarrhea cases between 1978 and 1986 with average temperature and negative association with water availability. Moreover, in Fiji (1978–1992), diarrhea cases were found to be positively associated with the changes in monthly temperature and with extreme rainfall. Another study by Ebi et al. (2006) in small island countries that also includes some of the Pacific countries examined the potential added risk posed by global climate change on dengue transmission using computer-based simulation analysis. The study showed that change in frequent and severe weather may change the range and prevalence of climate-sensitive diseases such as malaria, dengue fever, and diarrhea.

Similarly, assessments on health impacts of climate change are also few. McMichael et al. (2002, 2003) conducted an assessment on health impacts in Oceana that showed consequent increase in heat- and flood-related deaths and injuries and increase in food-borne and waterborne disease in the past years. Another assessment on the health impacts on Canadians in Canada showed increase in waterborne and vector-borne disease with increase in climate variability (Health Canada 2008). On the other hand, a review of historical practices in water-related infectious disease research in developing country's context shows lack of data, limited relevant indicators, and inadequate understanding of factors that cause water-related infectious disease due to climate change (Batterman et al. 2009).

Few assessments have looked into the health impacts on gender. One such assessment is WHO's climate-induced gender health risk assessment that shows indirect impacts such as women's caregiving work, health hazards associated with women traveling long distance for water collection, as well as mental health problems for both men and women (WHO 2010).

Most of these studies have not looked into the potential adaptation measurements for health impacts of climate change. Mostly adaptation measures have been anticipated and proposed within the sectors such as water, agriculture, infrastructure, and engineering (ADB 2011). Moreover, study recommendations for interventions and adaptation are more focused on developing the scientific or economic strategies and less focused on the possibility and kind of contribution the public health sector could provide such as delivery of health services.

Nonetheless, these studies and assessments have provided a good foundation for designing a potential framework and scenario for future studies and assessments that would look into empirical facts to understand whether the projections for the developing countries have any significant impacts or not and the appropriate adaptation measurements for the same. However, it is also important to note that human health impacts of climate change may not be easily detected due to adaptation and non-climatic factors that often determine the level of impact especially in high-income, developed countries where adaptation measurements are well developed. Based on data from 34 stations in the Pacific, a study shows increase in surface air temperatures by 0.3–0.8° C during the twentieth century (Nurse et al. 2001). Some of the observed changes include increased coastal erosion, more saline soils, shifting fishing grounds, and more droughts and water shortages. Models also project the greater climate variability (such as more extreme high temperature and precipitation events). El Niño events are also supposed to strengthen short-term and interannual variations.

The "already overextended" health system and the existing health impacts from noncommunicable diseases are expected to further deteriorate with the climate change-induced health impact that increases the incidence of communicable diseases. Infectious diseases such as malaria, dengue, and diarrhea are regarded as the major health impacts of climate change in the Pacific (Comrie 2007). Moreover, over 20 % of deaths due to unsafe water and poor and inadequate sanitation hygiene are also caused by the climate change impacts such as flooding and drought. This has also strained the majority of the Pacific's public health system (SOPAC 2008).

El Niño events in 1997–1998 caused various health impacts in some countries of the Pacific region. They included health problems such as diarrhea and nutrition deficiency caused by decrease in water availability and agricultural production. Gender-related health impacts were also found. Pregnant women suffered from micronutrient deficiencies in places in Fiji where there was extreme drought (Ebi et al. 2006).

The Pacific region lies in tropical and subtropical zones with weather that is susceptible to the transmission of communicable disease such as malaria which can become worse with the change in climatic condition, inadequate infrastructure, poor waste management practices, and poor public health practices (WHO 2002). In addition, weather and climatic factors coupled with social aspects such as culture and traditions also contribute to disease prevalence.

There was an outbreak of dengue fever in Fiji coinciding with the El Niño event where 24,000 out of the 856,000 population were affected with 13 deaths. Although dengue is frequent in Fiji, the large outbreak was caused by the El Niño event that facilitated mosquito growth and caused extreme health impacts, also affecting the neighboring nations in the Pacific (Ebi et al. 2006).

Other related issues may hamper the overall health in times of climate change impacts such as the vulnerability and access to health services in times of climate change events.

The definition and understanding of the concept "vulnerability" also varies. For example, in the studies of climate change impacts and infectious diseases, vulnerability may be understood as a state of increase of adverse potential outcome on the health, according to direct exposure of certain climatic disasters or the indirect and gradual influence of extreme weather-related environmental hazards on particular diseases that affect health (Woodward et al. 2001).

Discussions of health-related vulnerability in a developing country such as those in the Pacific could be more understood by the concept of "poverty and inequality" that is often associated with the vulnerability concept in low-income countries (Brooks 2003). It is understood as the lack of access to resources and a status of dependency and disadvantage.

Although vulnerable populations have been identified in some studies in the Pacific region, the consequent impacts on specific population group have been left unexplored. Health outcomes such as nutrition deficiency due to food shortage (drought or heavy rainfall) could affect group of people in different ways according to their gender, age, economic status, ethnicity, and geographical location (WHO 2010). In some Pacific countries, women often eat last and the least and are suffering from poor nutrition and anemia. In times of food shortage, they may suffer from severe malnutrition and anemia, which has been found in some South Asian countries, like Nepal (Regmi 2007, 2009). Moreover, women in many rural societies in the Pacific are the providers of water and food to their family and are responsible for providing care to the sick, elderly, and children in the household (Brody et al. 2008). Thus, climate change impacts such as water and food shortage and increases in vector- and waterborne diseases not only affect women's health in general but affect their physical and mental well-being as the burden of diseases, caregiving responsibilities, and work increase. Women and girls often walk miles in search of water sources in the forest areas which could be hazardous for health and could be physically burdensome. Pregnant and nursing mothers as well as infants and children could be at high risk at such times (Regmi 2007).

IPCC defines adaptation as "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects." Health adaptation measurements could be designed and undertaken in certain context and situation by certain group of people depending on their capacity and ability, often determined by not only the environmental but also socioeconomic, demographic, and individual factors (WHO 2003). In addition to this, the geographical location and its physical as well as socioeconomic environment also determine the relationship between certain diseases and climate change indicators and the degree of their prevalence. For example, low-income or less developed countries and those in low-lying coastal areas such as the Pacific island countries are understood to be affected by vulnerable diseases such as malaria, dengue, and diarrhea, while health impacts such as heat waves and air pollution are supposed to be high in large cities such as those in developed countries (WHO 2003).

In health terms, adaptation is a measure of what could be designed to minimize the negative health impacts of climate change that may arise in the future and maximize any positives that may occur. An assessment of historical and current vulnerability and adaptive capacity is necessary to plan not only future but current measures. The assessment will provide a thorough understanding of what adaptive measures are needed for the management of potential health effects of climate change Pittock (2003).

Seasonal forecasts have been often used to increase adaptation to climate variability, including weather disasters in some of the states of the Pacific. For example, the Pacific ENSO Application Center (PEAC) warned governments, when a strong El Niño was developing in 1997/1998, that severe droughts could occur and that some islands were at unusually high risk of tropical cyclones (Hamnett 1998). The projects, such as public education and awareness campaigns, were effective in reducing the risk of diarrheal and vector-borne diseases. For example, despite the water shortage in Pohnpei, fewer children were admitted to the hospital with severe diarrheal disease than normal because of frequent public health messages about water safety. However, this did not contribute to the reduction of all negative health impacts, such as micronutrient deficiencies in pregnant women in Fiji.

Research Method and Limitation

The findings of the study are based mainly on literature review. Initially, the study was supposed to analyze the association of climate change and its impact on health using secondary data analysis, but due to lack of access to data, as well as the limitation of time to collect data, the study chose to make a case study instead. The study analyzes the case study of Papua New Guinea (PNG) through information gathered from literature review and secondary data.

Results and Discussions: PNG Case Study

Although various reports (IPCC 2007; WHO 2003) show that climate change impacts could be severe in other Pacific countries, the health-related indicators show that related health impact could be more severe in PNG (see Tables 1 and 2). Hence, the study focuses on PNG as a special case to understand the impacts. It will focus on the climate change-induced health-related vulnerability issues in PNG, types of climate change impacts on health on PNG population, and the adaptation measures undertaken so far.

Climate Change-Induced Health Vulnerability in PNG

Located in the Pacific Ocean, Papua New Guinea (PNG) is one of the least developed countries (LDC) with low economic and human development indicators that often affect the health of the major population (UNDP 2009). The health sector has deteriorated since the 1980s due to neglect of the health system, especially in rural areas, where 87 % of the population live. An estimated 40 % of rural health facilities have closed or are not fully functioning (ADB 2011). The country has

Table 1 Environmental burden of disease in the Pacific

Country	Improved water	Improved sanitation	Diarrhea deaths per year	Diarrhea DALYs/ 1,000 capita/ year	Main malaria vector transmission	Main other vector transmissions	Malaria deaths/ year	Environmental burden on diarrhea (lowest, 0.2; highest, 114)	Environmental burden on malaria (lowest, 0.0; highest, 32)	% malnutrition
Australia	100	100	–	0.2	No transmission	None	NA	0.2	0.0	NA
Cook Islands	94	100	–	2	No transmission	None		2.3	–	NA
Fiji	47	72	<100	1.5	No transmission	*Aedes aegypti* – dengue		1.9	–	NA
Kiribati	65	40	–	10	No transmission	*Aedes aegypti* – dengue		10	0.2	NA
Nauru	NA	NA	NA	NA	No transmission	None		30.	–	NA
New Zealand	NA	NA	NA	NA	No transmission	None		0.3	–	NA
Niue	100	100	–	0.5	No transmission	None		0.7	–	NA
Palau	85	83	–	2	No transmission	None		2.2	0.0	NA
PNG	**39**	**44**	**2,100**	**13**	***A. farauti*, *A. punctulatus*, *A. bancrofti*, *A. annulipes*, *A. koliensis***	***Culex pipiens***	**45 [25–67]**	**13**	**2.5**	**44**
Samoa	88	100	–	3.3	No transmission	*Aedes aegypti* – dengue		3.6	0.2	9
Solomon Islands	70	31	200	14	*A. farauti*, *A. punctulatus*, *A. koliensis*	*Aedes aegypti* – dengue		15	0.6	NA
Tonga	100	96	–	3	No transmission	*Aedes tongae*		3.3	0.1	NA

Source: WHO Global Health Observatory Data Repository 2011

Table 2 Environmental burden of disease-related deaths in the Pacific

Location	Time period	Water-, sanitation-, and hygiene-attributable deaths ('000)	Water-, sanitation-, and hygiene-attributable deaths ('000) in children under 5 years
Cook Islands	2004	1	1
Fiji	2004	42	10
Kiribati	2004	23	20
Marshall Islands	2004	13	12
Micronesia (Federated States of)	2004	15	12
Niue	2004	0	0
Palau	2004	1	1
Papua New Guinea	**2004**	**2,833**	**2,615**
Samoa	2004	17	16
Solomon Islands	2004	74	58
Tonga	2004	8	8
Tuvalu	2004	2	2
Vanuatu	2004	16	13

Source: WHO Global Health Observatory Data Repository 2011

widespread poverty and weak health indicators, particularly for maternal and child health. Asian Development Bank's (ADB) report shows the infant mortality rate to be 47 per 1,000 live births and the maternal mortality rate to be 250 per 100,000 live births. The main health problems continue to be communicable diseases.

PNG is also home to several environmental disasters and climate change impact that threaten its fragile coastal and forest areas which often serve as a means of livelihood to the poor rural population. The socioeconomic vulnerability coupled with the geographical vulnerability has made climate change threat a serious problem in PNG, especially for the rural population which depends on natural/forest resources (fisheries, mangroves) and subsistence agriculture for their livelihood. When these resources are threatened, food insecurity increases and ultimately affects the health (nutrition) and well-being. Moreover, the interannual variability in climate change such as changes in temperature, precipitation, and humidity also leads to the contribution of various vector-borne, waterborne, and food-borne diseases that multiply with water shortage as well as poor water management and sanitation.

Increase in the prevalent infectious disease such as malaria further affects the already overburdened health system of PNG that is suffering from poor access and delivery issues. A survey conducted by Papua New Guinea Institute of Medical Research (PNGIMR) predicts the rise of population prone to malaria risk from 65 % to 95 % by 2100. Aside from three countries, namely, PNG, Solomon Islands, and Vanuatu, the other Pacific nations are assumed to be free of malaria. However, the 2006 White Paper on aid in the Pacific and Southeast Asia shows malaria cases to be highest in PNG as compared to Solomon Islands and Vanuatu (see Fig. 1)

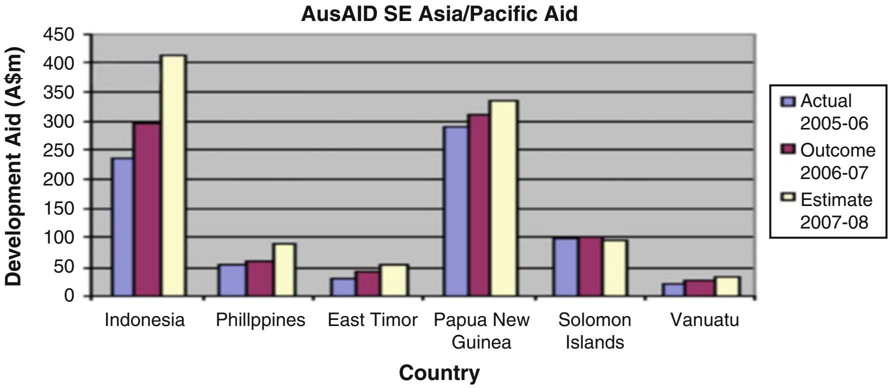

Fig. 1 Malaria cases in AusAID-funded countries in SEA and the Pacific (Potter 2008) (Source: 2007–2008 Foreign Affairs and Trade (AugAID) Budget, "Appendix – AusAID Country and Global Program")

(Potter 2008). While the major prevalence of effects of malaria is expected to be mostly in coastal provinces, the PNGIMR survey warns that climate change puts even other locations such as highland at risk of contracting the disease. WHO has recorded 4,986 malaria cases in the Western Highlands province of PNG in 2005, compared with 638 cases in 2000. The malaria epidemic of 1997–1998 in the highlands which was predominated by *P. falciparum* is consistent with a response to anomalous warming and precipitation, suggesting that malaria trends in PNG may follow similar trends to those of the East African highlands (Githeko 2009). The burden of malaria is likely to increase in PNG with climate change. Malaria has been diagnosed as the major indicator of mortality rates in Papua New Guinea, with around 1.7 million cases in 2003 and 700 mortality cases in 2007. WHO reports that since many cases in remote/rural areas are not recorded properly, the number of cases could be even higher.

However, there is a gap in the understanding of the socioeconomic and demographic differences in the risks to the climate-induced disease that has important implication for understanding the health benefits of the vulnerable population as well as the challenging role and responsibilities of public health sector in meeting the needs and interests of the vulnerable. Similarly, freshwater fisheries, mangroves, and subsistence agriculture which are often threatened by climate change impacts provide food to many people living in coastal communities in PNG, which may consequently affect their nutrition level with unavailability of adequate and nutritious food.

Although there are no major droughts in PNG, in 1997/1998 there was a major drought that took place in many Pacific nations including PNG. Moreover, some minor droughts also occurred in 1914 and in 1941, 1965, 1972, 1982, and 1987 associated with the El Niño event which has been increasing since 1914. About 40 % of PNG's rural population faced food insecurity and water shortages in the 1997/1998 drought associated with the El Niño event. However, there was a low death toll due to the coping strategies followed by the people through initiatives such as foraging in the forest, trading, and activating extended family networks. Although there were few deaths, it increased in the rural part where people had to live longer without enough food and safe water. Few people suffered from diarrhea and mostly from severe malaria.

There is a lack of proper knowledge on the climate change-induced health impacts such as those from drought and the responding mechanism to such impacts. Additionally, considering the nature of health impacts of such causes to be arising through indirect pathways, it is difficult to model the impacts and anticipate and prepare appropriate public health measures. Most of the identified adaptation measures fall under the agricultural sector which is insufficient toward meeting certain needs and interests of the vulnerable populations.

PNG also lacks sex disaggregated data as well as qualitative, demographic, and geographical knowledge on gender-related health impacts given the evidence that the higher prevalence of climate-sensitive disease such as malaria and malnutrition is found more among pregnant women. Maternal and child mortality often has been cited as the result of these diseases.

The emerging threats to the health of the vulnerable groups from factors other than disease such as physical access to health-care services in the rural, coastal, and agricultural part of PNG where the major population lives are crucial to understand and overcome. The increases in the prevalence of malaria and malnutrition are some of the outcomes of the increase in temperature and rainfall and the El Niño-influenced drought events in PNG. This has also increased the vulnerability of people with less capacity and physical access to seek health care and adapt to as well as those with less immunity to fight the transmission of diseases, such as women and children.

Identifying Vulnerable Population, Location, and Key Indicators for PNG

In developing countries such as PNG, vulnerability is often associated with poverty and inequality. PNG holds large population (6.8 million) as compared to other Pacific nations and covers around 83 % of the total Pacific region. It also ranks lowest in the Human Development Index as compared to other Pacific countries (UNDP 2009). High mortality rate and lower literacy rate have also been the key indicators of vulnerability in PNG.

PNG has a total population of approximately 6.8 million, and the majority of these (87 %) live in rural areas where access to markets, services, and income-generating opportunities is limited. Agriculture, fishing, community forestry, and mangroves are the main sources of livelihood in the rural areas (World Bank 2012).

Over 50 % of the rural population lives below the poverty line. Not only the insufficient awareness or adaptation of climate change impacts but also other socioeconomic indicators such as poverty, limited and expensive access to inputs and markets, poor infrastructure, ineffective extension services, and limited access to credit, all contribute to the vulnerability of the PNG's rural population.

Climate variability and change are set to accelerate the occurrence of landslides, soil erosion, deforestation, and loss of biodiversity, as well as increase occurrence of recurrent floods and droughts. However, little is known on the health impacts of climate change in PNG. There has been concern and expectation that malaria may spread from coastal areas to highlands as isotherms (climate particular) are expected to rise doubling the effect of CO_2, the main emitter of GHG and major contributor to climate change impacts (McGregor 1990). However, PNG remains incapacitated to adaptation as it lacks a good public health infrastructure and delivery service, a good community involvement and practice of control measures, and a good disease surveillance system (Lifson 1996).

Few studies in PNG have mapped climate, environment, and nutritional health outcomes at national or local level. Temporal studies can also reveal vulnerability to interannual climate variability or the effect of the El Niño Southern Oscillation. Study in Papua New Guinea has shown that women living in poorer-quality environments produce less food, suffered chronic malnutrition, and had children with lower birth weight (Allen 2002).

The continuous occurrence of El Niño has been associated with high shortages of food. In the year 2002, a technical assessment on the impact of El Niño conducted by the National Agricultural Research Institute (NARI), Australian Aid (AusAID), Australian National University (ANU), and National Disaster Management Office (NDMO) reported not only rural and coastal areas but also highland areas to be highly prone to El Niño-related health impacts. The El Niño weather pattern that runs from June to September in PNG is an important source of drought and eventual shortage of food supplies. The people in rural and highland areas are particularly affected by the impacts of drought as their traditional subsistence agriculture does not cater for such extreme weather patterns.

Framework on Health Impacts and Vulnerability for PNG

Based on the literature review and information gathered, the study has come up with a framework on health impacts and vulnerability for PNG (Fig. 2). The framework shows that PNG's major climate change scenarios are drought and increase in rainfall/temperature. One pathway driving the impacts on health includes food insecurity through drought that leads to malnutrition. Another is transmission and reproduction of disease vectors caused by increase in rainfall in normally dry areas and temperature that leads to malaria sickness. These health problems may decrease with the development of adaptive capacity and appropriate adaptation measures. Similarly, there are three levels of vulnerability that could affect the PNG population. At the individual (micro) level, vulnerability is caused by individual, socioeconomic, and geographical indicators such as less nutrition and care, low income, disability, and living in poor condition. At the community (meso) level, vulnerability is associated with the group of people having less access to social support, lack of community health posts, and less community awareness and education programs. At the national (macro) level, vulnerability is defined by the strength and weakness of

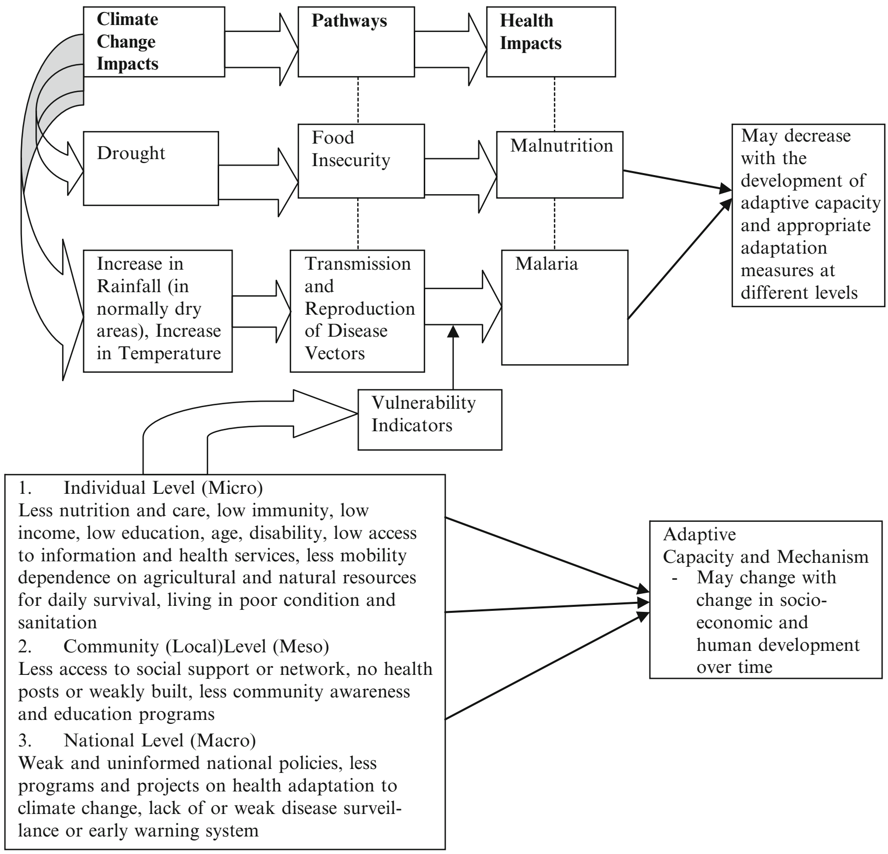

Fig. 2 Health impacts and vulnerability in PNG (Source: Author's Work)

government/state such as weak and uninformed policies and less programs and projects on health adaptation to climate change. The adaptive capacity of these vulnerable individuals, communities, and states may change with change in socio-economic and human development over time.

Adaptation Measure for PNG at Different Levels

The different levels of vulnerability cause different types of impacts (Fig. 3). Hence, the adaptation measures should also be developed with understanding to these levels. At the individual level, a cheaper adaptation measure could be undertaken such as during malaria breakouts, one can use mosquito nets or mosquito spray to protect oneself. At the community level, the measure could be a little expensive as it will include meso-level programs such as vector control, vaccine, and educational

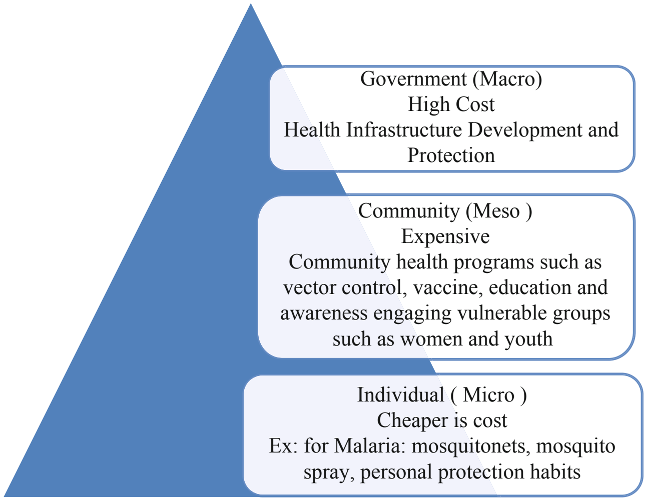

Fig. 3 Levels of adaptation (Source: Adapted from Department of Health Western Australia 2008)

programs. At the governmental level, the macro issues such as infrastructure development protection affect the vulnerability; the cost of adaptation measure is also high and thus needs enough fund and support.

Limitation and Future Research

Human health-related risks have been recently diagnosed under the climate change vulnerability and adaptation issues in developing countries, but there are very few studies especially in the Pacific region and particularly in Papua New Guinea (PNG) where the vulnerability is very high.

Few efforts have been made to understand the observed differences in vulnerability of different socioeconomic and demographic groups in the Pacific, particularly in PNG given the fact that PNG covers the highest population in the Pacific that differs in socioeconomic, geographic, and political order. This has important implications for developing public health adaptation measures, policy making, and planning. Similarly, most of the support has concentrated on the technological and scientific measures for adaptations to other affected sectors such as agriculture and water sources with very few supporting the social sector, such as health. Existing studies/assessments are based on projections, and very little is known on the current impacts with very few successful adaptation measurements undertaken so far.

The study points out the following limitations and gaps in research and support:

- Health issues in the Pacific and particularly in PNG are less informed but critical for the growing population especially the youth and women considering the past, current, and future prospects of climate change impacts.

- Less resources to understand the link and pathways to health impacts of climate change due to lack of research and information sharing on the ground.
- Health sector and its role and responsibilities have not been identified properly.
- Less support has been provided to the health sector, due to importance given to other socioeconomic issues such as poverty, water crisis, and food insecurity.

The study concludes that the Pacific region and particularly PNG lack existing datasets and knowledge to build the association of climate change and health impacts that is based on historical and current knowledge and information. Hence, vulnerability assessment would be the first step to understand certain impacts in certain contexts which will build the foundation of empirical knowledge that could be obtained through either qualitative assessment based on primary data or quantitative analysis using secondary data. Based on the results, certain scenarios then could be developed to make future predictions and anticipate and design adaptation measures. Overall, the study came up with the following recommendations for research and policy:

- Enhance and improve capacity and knowledge of the population and particularly the vulnerable groups by providing education, training, and vocational programs.
- Development and improvement of information sources through collection of socioeconomic (e.g., age, gender, income) and geographic data/indicators.
- Strengthening of public health sector's roles by encouraging participation of health clinicians.
- More support to public health sector on designing adaptation measures to climate change-induced health impacts.
- Physical access to health-care services during climate change impacts such as loss of infrastructure and transportation needs to be improved.

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Guiding Regional Climate Adaptation in Coastal Areas

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Abstract

Global climate change will have significant impacts on natural systems and human societies throughout the world. Therefore, climate adaptation strategies need to be developed at multiple scales. The Interreg IVB project "Climate Proof Areas" (CPA) has focused on climate adaptation at a regional scale in twelve pilot areas across four North Sea countries. It showed that the regional scale provides challenging opportunities of cross-sectoral climate adaptation. This paper gives an overview of experiences from the CPA pilot studies and embeds these in a generic approach for regional climate adaptation. Attention is paid to typical issues of coastal regions: water management, coastal protection, freshwater supply, land

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use, and spatial planning. Based on typical challenges of climate adaptation such as low sense of urgency, high degree of uncertainty regarding future development, and decision-making on a long term, a number of illustrative components are discussed which can contribute to the guidance of regional climate adaptation. These components cover different themes including communication issues, physical solutions, knowledge, and process-oriented approaches and result in a so-called adaptation toolkit. Finally we draw conclusions and derive recommendations about how certain approaches and policies at different levels can contribute to successful regional climate adaptation in coastal areas.

Keywords
Climate change adaptation • Regional scale • Pilot studies • Adaptation toolkit • Policy recommendations

Introduction

Climate change is one of the key challenges in recent environmental and societal research and studies on sustainable development. The Intergovernmental Panel on Climate Change (IPCC) has stated that global warming has accelerated significantly in the second half of the twentieth century and that humans have caused the dominant part of global warming (IPCC 2013). The envelopes of reasonable climate scenarios project further global warming until the end of the twenty-first century. Even if greenhouse gas concentrations will not increase from the level reached in year 2000, global mean temperature will continue to rise by approximately 0.1 °C per decade during the twenty-first century due to delayed response of slow components in the climate system (van den Hurk and Jacob 2009). For the North Sea region, in addition to rising temperatures and sea levels, an increasing rainfall variability is expected which is likely to cause droughts as well as flood events in the future (IPCC 2013; Verhofstede et al. 2011). Therefore proactive strategies are required to react to future climate change.

Based on these commonly accepted facts, science and society are debating on how to react to climate change. Two main complementary strategies are basically agreed on: (1) to mitigate future climate change, e.g., by reducing the emission of greenhouse gases and (2) to adapt to those changes which cannot be mitigated. While mitigation needs to be implemented on a global scale, adaptation to climate change is a local to regional scale issue (Füssel 2007). Independently of the effectiveness of future mitigation, adaptation to climate change is necessary if such climate change exceeds current climate variability. Adaptation to climate change, therefore, has raised public interest in recent years, mainly driven by climate-related disasters (Füssel 2007; Krysanova et al. 2010). As a consequence, preliminary national frameworks have been established towards the development of national adaptation strategies (e.g., for Germany: Bundesregierung 2008).

Due to the increasing relevance of adaptation to climate change, the scientific community as well as the government has paid more attention to this issue in recent years. General concepts and approaches for adaptive planning were introduced (e.g., Füssel 2007) and analyzed with regard to regional possibilities for and limitations of climate change adaptation (e.g., Kabat et al. 2005; de Bruin et al. 2009). Adaptation strategies were compared among different regions and river basins (e.g., Krysanova et al. 2010) as well as their recent status in adaptation planning (e.g., Huntjens et al. 2010). Most studies agreed that adaptation needs to be at a regional scale (e.g., Wesselink et al. 2009) and consider different issues (de Bruin et al. 2009; Veraart et al. 2010) such as nature protection, agriculture, economic development, and water management. Water management is of particular importance in coastal environments (Woltjer and Al 2007; Wesselink et al. 2009; Veraart et al. 2010).

Nevertheless the question remains still open how to organize such an adaptation process at the regional scale. Considering the importance of water management in coastal environments, climate adaptation is required to be in accordance with the European Water Framework Directive (EC 2000), an Integrated Coastal Zone Management (EC 2002, 2013), and the European Flood Risk Management Directive (EC 2007). These EC documents emphasize an intense involvement of stakeholders in terms of participation and collaborative planning of management plans. Guiding principles are required to efficiently organize the regional adaptation process based on practical experience. At present, a gap between the mostly well-figured out adaptation plans at a national level and the implementation in the regional and local development plans can be observed in the North Sea countries. In addition, current regional and local development plans often do not consider the effectiveness of planned measures with respect to climate change (adaptation). Such experiences have been collected in the framework of the Interreg IVB North Sea Region Program project "Climate Proof Areas" (CPA) which focused on climate adaptation on a regional level in a number of pilot areas in four North Sea countries (Germany, the Netherlands, Sweden, the UK). Based on the experiences from twelve pilot studies, an *adaptation toolkit* has been developed as well as a collection of *recommendations* and *guiding principles* for regional adaptation, based on good practice examples. Such guiding principles consider typical challenges of climate adaptation such as low sense of urgency, high degree of uncertainty regarding future development, and decision-making on a long term.

While it is not feasible to develop a "cookbook" for regional climate change adaptation, the *adaptation toolkit*, *recommendations*, and *guiding principles* consider the limiting factors of adaptation processes and aim at achieving consensus of as many actors as possible on the basis of the best available knowledge and experience.

This chapter is structured in order to (1) briefly introduce the pilot studies, (2) characterize regional climate adaptation along coastlines, (3) highlight some adaptation-specific lessons learned from the pilot studies, (4) introduce the main elements of the adaptation toolkit, and (5) finally derive recommendations and draw conclusions about how certain approaches and policies at different levels can contribute to successful climate adaptation in coastal regions.

Pilot Studies

Within the CPA project a number of pilot studies provided information and experience relevant for regional climate adaptation (Adriaanse et al. 2011). The case areas were located in four countries: Germany, the Netherlands, Sweden, and the UK (Fig. 1).

Case Area in Germany

The German case area within the CPA project was the Wesermarsch County in the north of the country, near the North Sea. A regional analysis of climate change-induced hydrological impacts served as basis for participatory problem analysis and the development of adaptation options (Bormann et al. 2009, 2012). Pilot studies and activities within this area concentrated on both rural and urban areas. Within the rural areas, attention was paid to climate change issues concerning the water management system, salt intrusion, and the drainage function for the low-lying hinterland, taking into account the consequences for agriculture, safety against flooding, and nature protection. Another important issue was coastal defense, because of the long dikes which surround the area and the possible consequences of sea level rise and higher flooding of the Weser River. For the urban areas of the county, different focus issues were identified. There, the connection was made with spatial planning solutions and possible investments in waterworks. Solutions for increasing water storage in urban areas were identified as well as interactions between the urban areas and rural hinterlands (Ahlhorn et al. 2011). Regarding both urban and rural areas, attention was also paid to the possible consequences of higher precipitation in the future and possible technical and planning solutions for increasing water storage capacity.

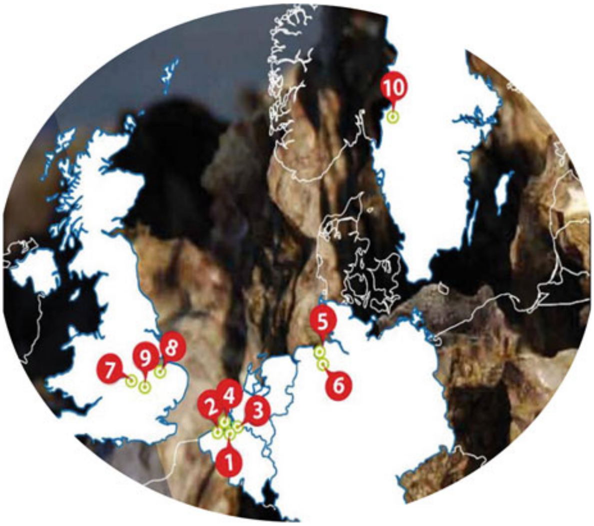

Fig. 1 Location of the pilot areas across the North Sea region

Case Areas in the Netherlands

Schouwen-Duiveland: The island of Schouwen-Duiveland is completely surrounded by dikes and dunes and connected to some of the main Dutch Deltaworks. It was used to study and demonstrate different potential solutions for climate adaptation in practice. A broad regional climate impact analysis provided the basis for a number of follow-up studies and projects within the area. Particular attention was paid to the adaptation of local agriculture to saltwater intrusion and changing freshwater supplies, new approaches for spatial planning and flood safety management, and new combinations of coastal defense, urban development, and cultural heritage.

Oosterschelde (Eastern Scheldt): Since the creation of the Oosterschelde storm surge barrier for coastal defense purpose, the ecological balance of most of the inhabited areas surrounding the estuary has been disturbed. Due to the altered tidal characteristics, the current area of sand flats within the estuary is becoming gradually smaller year by year. Climate change will accelerate this process due to sea level rise. As a result the unique ecological features of the Oosterschelde estuary will disappear until the end of the twenty-first century. To impede this process a number of experiments and pilot projects were executed within the area, such as sand nourishment and the creation of shellfish reefs.

Case Area in Sweden

The Swedish case area within the CPA project was located in the municipality of Arvika, located near Lake Glasfjorden. The area and its surroundings have been identified as an area particularly at risk to flooding as a result of climate change. The water level adjacent to Arvika is partly dependent on the water level of the lake and the water flow of the river Byälven. In Arvika there have been damaging floods (e.g., year 2000). Scenario-based impact studies revealed that climate change will have an impact on the long-term behavior of inflow patterns into the lake, impacting flood risk. Climate change is expected to result in more frequent and severe events, unless proactive steps are taken. The CPA project has analyzed the possible impacts of climate change and identified the consequences for the local infrastructure and storm water drainage systems (Olsson et al. 2013). To cope with future events, a number of physical adaptation solutions have been designed, and implementation has been guided within the CPA project.

Case Areas in the UK

Wicken Fen: Wicken Fen is one of the most important low-lying wetlands in Europe. Below sea level, it is also one of only a few surviving unimproved wetland fens in the East of England. The CPA project has contributed to create a vital green lung and a recreational resource for the nearby highly urbanized growth area of Cambridge. The innovative activities at Wicken Fen not only prepare this vitally important natural site for climate change, but it also makes the area more attractive for tourism and recreation. CPA activities contributed to four major challenges: creating new wetland mosaic habitats, developing water management plans, gaining a clear understanding of the potential of topography and re-wetting peat soils to reduce carbon loss from soil oxidation.

Titchwell Marsh: This pilot project dealt with raising awareness of the need for innovative forms of flood defense as part of adaptation to the impacts of climate change. By raising public awareness and understanding of the issues surrounding climate change and its impacts on coastlines, the CPA project supported the Titchwell Marsh Coastal Change Project. CPA has contributed to educate the public and stakeholders about the necessity of innovative flood management techniques. The main focus has been on communication issues and the construction of an innovative visitor hide, providing a fantastic opportunity for the reserves 80,000 visitors a year to see a managed realignment scheme at first hand and experience how the habitat develops over time. The Coastal Change Project plans to move parts of the present sea defenses, improving it in other areas, allowing the sea to reclaim some land, while protecting the freshwater habitats.

Great Fen: This project created an opportunity to reconnect and buffer two National Nature Reserves, providing a solution to flood risk problems to protect surrounding farmland and property, stop the loss of carbon to the atmosphere, and sequester carbon from it. With regard to these issues, this project anticipated effects of climate change and ensures that the wider area as a whole is climate proof on the long term. The pilot studies and activities concentrated on understanding flood risks, sustainable water resource management, and conservation of the heritage and natural resources. Attention was also paid to a planning framework that supports tourism and the economy.

More detailed information on the pilot projects with CPA is available at www.climateproofareas.eu.

Characteristics of Regional Climate Adaptation

The CPA project was connected to a cross section of a wide variety of projects, initiatives, studies, and stakeholder processes aiming at climate adaptation in a region or area (Adriaanse et al. 2011). Based on the outcomes and experiences of these activities, a number of specific issues can be summarized that are characteristic for regional climate adaptation in general and specific for coastal environments.

"Typical" Climate Impacts in Coastal Regions

In coastal regions the most relevant impacts of climate change are related to the following issues:

- Coastal defense and flood safety structures are primary elements to protect coastal areas against floods, in particular with regard to built-up and inhabited areas, but also rural. Increasing flood risks caused by climate change is related to the expected sea level rise, higher precipitation, higher river discharges, and in some areas ground subsidence. Already today waterlogging is a big problem in built-up and rural areas due to increasing precipitation, heavy peak showers, and groundwater flow, making enhanced drainage infrastructure necessary.
- Natural areas and ecological balance of coastal areas are of high value. Large protected areas have been established, aiming at the conservation of wetlands, tidal areas, and estuaries. A complexity of changes within climate, water management, and land use will cause increasing hazards for nature conservation areas and valuable ecological systems.
- Smart water management is essential for agriculture. Coastal soils are very productive at tidal coasts; therefore, agriculture is of high societal importance. Due to climate change and current water management, there is an increasing probability of droughts and ongoing salt intrusion in regional surface and groundwater systems. Increased effort will be required to maintain freshwater supplies for agriculture and, in some cases, drinking water as well (Faneca Sanchez et al. 2012).
- From the perspective of the tourism industry, coastal regions are highly attractive. Climate change will bring threats and opportunities for leisure and tourism. Expected rising temperatures and changing precipitation patterns will influence leisure and tourism. Investment programs in coastal defenses and improvement of nature reserves can offer new opportunities.

Although climate change studies often refer also to increasing heat stress in cities, this has not been identified as a relevant issue within the CPA case areas, probably because of the absence of larger towns within these cases and the proximity of nearby "cooling" seashores.

Many climate change impacts deal with water issues that have an influence on local and regional land use (e.g., Woltjer and Al 2007; Veraart et al. 2010). Therefore, in most coastal regions climate change has serious consequences for current water management strategies and spatial planning on a local and regional scale. Combinations of land use and water management, or multiple land use options, require additional attention, e.g., combinations of coastal defense with urban development or water storage in combination with improving ecological balance, nature conservation, and supporting tourism.

Decision-Making on a (Very) Long Term

Climate change will happen very gradually during the twenty-first century. As a result, climate proofing is a process that will continue in the long term. This must be remembered when taking measures for current problems at hand. It is vital that decisions made in the short term do not reduce adaptive capacity in the long term.

Interaction Between Different Scales

Climate adaptation must accommodate interactions between local, regional, national, and international scales. First of all, climate change is a worldwide challenge, but the impacts (and how these are perceived) are different for different countries, regions, or local areas (Verhofstede et al. 2011). It is also perceived that the coordination of climate (change) adaptation strategies between different policy levels is often inadequate, including a lack of bottom-up and upscaling mechanisms. Measures, solutions, and regulations on the international and national scales may affect the regional scale and vice versa. Additionally, measures taken in one area can affect another area. Therefore, more detailed site-specific information and data is required than what is actually available on global and national scale.

Uncertainties Due to (the Sum of) Incremental Deviations

An almost inherent aspect of climate adaptation is the uncertainty that comes with the predictions and scenarios for the future. This is not only the case for climate scenarios but also for the socioeconomic development and the (un)foreseeable changes in the views of the involved parties. *What may be a problem today, doesn't necessarily have to be a problem in 2050 or even 2100*. Especially on the regional and local scale, there is often a lack of relevant scenarios regarding climate change impacts as well as future socioeconomic development.

In order to be able to deal with the uncertainties on the long term, the Dutch Delta program has introduced the principle of adaptive delta management. Key elements in adaptive delta management are (http://deltacommissaris.nl/english/topics/adaptive_deltamanagement):

- Linking short-term decisions to long-term issues in the fields of water safety and the freshwater supply
- Adopting a flexible approach in the possible solutions
- Working with several strategies and allowing for switches (adaptation tracks)
- Interlinking various investment agendas

Weak Commitment and Low Sense of Urgency

Climate change is a slow process. Therefore in many cases the sense of urgency is still low, especially at the regional and local level. Consequently, climate adaptation is often perceived as an abstract challenge resulting in little commitment from parties to actively participate in the process of climate proofing. The initially unstructured, multilevel, and multi-sectoral character of climate adaptation makes it difficult to identify which parties or stakeholders should be committed or responsible and to set widely agreed deadlines on decision-making. The necessity to develop and maintain consistent strategies

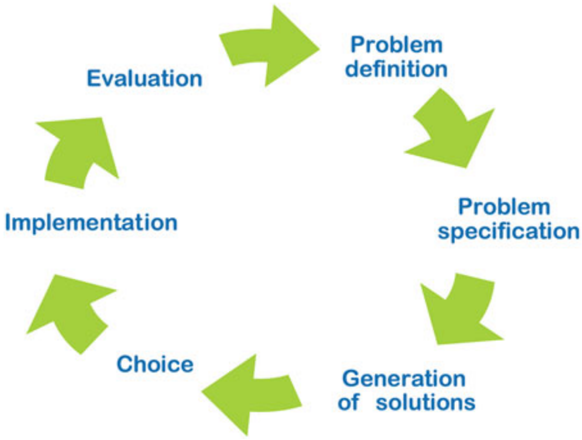

Fig. 2 Elements of the problem-solving cycle (Changed after Bots 1997; Simon 1977)

and to implement disputable measures also requires commitment from decision makers on higher levels within organizations.

Process Rather than a Number of Projects

Climate adaptation policy has to cover the gap between long-term effects and short-term decision-making. Therefore, and because of the often unstructured, multi-sectoral, and multilevel character and the possible involvement of many different stakeholders, climate proofing has to be considered as a process rather than a sequence of projects. In most cases the different phases of this climate proofing process are aligned with a "traditional" problem-solving cycle (problem definition, problem specification, generation of solutions, choice, implementation, evaluation, and back again to problem definition; Fig. 2) that is often referred to form the perspective of policy processes. While climate proofing does not tend to follow straight paths through the different phases of this cycle, the distinct phases can very well serve as a framework to describe the process and practices connected to it.

Lessons Learned from Pilot Studies

Emerging from the pilot cases and studies within the CPA project (Adriaanse et al. 2011), a number of practices and measures were identified as being potentially successful in contributing to regional climate adaptation. These can be tools, methods, physical measures, or any kind of practices that deal with one or more of the characteristics of regional climate proofing as part of the problem-solving cycle. They served as good practice examples for the development of the "adaptation toolkit for the North Sea Region in a changing climate" (van Oostrom et al. 2011) developed in the framework of CPA.

Physical Measures and (Physical) Planning Solutions

The CPA project paid attention to a large variety of possible concrete physical and planning solutions, connected to the "typical" climate impacts as presented in the previous section. Although not every solution is already implemented, the following examples illustrate the character of the different contributions to climate change adaptation. They are structured with regard to some of the main climate adaptation-related challenges on coastal regions: (1) coastal defense and flood safety, (2) water management, (3) nature protection, (4) agriculture, and (5) tourism.

With regard to *coastal defense and flood safety*, the different pilot studies suggested a wide spectrum of measures including removable storm surge barriers (Arvika); realignments of coastal defenses connected to habitat development (Titchwell Marsh); sand nourishment; creation of shellfish reefs and "hanging beaches," also connected to habitat development (Oosterschelde former estuary); multifunctional sea defenses combining flood safety with urban reconstruction, cultural heritage, and nature conservation (Schouwen-Duiveland); regional strategies for so-called multilayer safety where land use characteristics and infrastructure become part of regional flood safety and related emergency facilities (Schouwen-Duiveland); and strengthening of the existing canal system and secondary embankments near and within urban areas (Wesermarsch). Some of these measures follow the current code of practice, but some are innovative and contribute to several targets of regional development.

With regard to water retention and management, suggested measures were to promote "green" roofs for temporary water storage in urban areas (Wesermarsch), temporary water storage in areas characterized by low damage potential in urban areas (e.g., ponds, parking areas, public parks) and polders in the rural surroundings (Wesermarsch), and the climate proof development of public sewage and drainage systems as well as private pipelines (Arvika).

With regard to *ecological balance and nature conservation*, a number of measures were suggested in combination with structures designed for coastal defense and flood safety (Oosterschelde; see above). Alternative solutions were creating new wetland mosaic habitats, developing water management plans, and re-wetting peat soils to reduce carbon loss from soil oxidation (Wicken Fen, Great Fen).

With regard to a*griculture and water supply*, measures included adapting agricultural land use to changing hydrological conditions and water management targets (Wesermarsch). Additionally, a study was conducted to adapt crops to increasing salinity, e.g., salt-tolerant potatoes (Schouwen-Duiveland). Two pilot studies aimed to improve water management by enlarging freshwater lenses above saline groundwater (Schouwen-Duiveland, Wesermarsch) and one by the exchange of water supplies between individual farms and areas with different water system characteristics (Schouwen-Duiveland).

Selected pilots suggested measures with regard to *leisure and tourism*. Synergies of nature protection and nature watching could be generated by the construction of recreational resources and a unique visitors' hide near attractive natural sites that are prepared for climate adaptation (Wicken Fen, Titchwell Marsh, Great Fen). In Schouwen-Duiveland, designs for sea defenses, in combination with urban redevelopment, new leisure zones and the reconstruction of cultural heritage were developed.

Knowledge-Oriented Practices

The measures mentioned above serve as good practice examples but cannot be implemented adequately without regional scale information on climate change impacts. Therefore, every CPA pilot area undertook a regional climate impact analysis, consisting of the following components:

- Translation of existing international or national climate scenarios to *regional climate scenarios* by dynamic or statistical downscaling techniques
- Model- and fact-based quantitative analyses of *climate change impacts* on physical (e.g., hydrology) and biological processes (e.g., ecology)
- Translation of expected regional *climate change impacts* on different economic sectors and land uses

For a more realistic assessment of the possible impacts of long-term climate change, analyses should also consider views on long-term socioeconomic development. Since such information often is not available on regional scale, available information from international (e.g., European Union) or national scenarios can be downscaled to the regional level. Another approach is to use the regional climate impact assessment as a starting point for developing regional long-term visions. These visions can partly be guided by conditioning national and European programs, policies, and regulations. Relevant examples are the Dutch national Delta Program (regarding flood safety and water supply), the EU Water Framework Directive, EU Floods Directive, and EU Bird and Habitat Directives.

In order to boost the regional climate adaptation process, an inventory of relevant national and European programs, policies, and regulations is recommended.

Process-Oriented Practices and Approaches

For a proper implementation of adaptation measures, in addition to physical- and knowledge-oriented practices, process-oriented practices and approaches are required. Such measures aim to involve communities and relevant stakeholders from the region. Practices and approaches are required in order to organize the adaptation process and to maximize the acceptance of the measures among those affected.

Participation is one of the main issues for successful climate adaptation. Involving different stakeholders such as decision makers, entrepreneurs, and the public is necessary to raise awareness, to achieve consensus, and to retrieve information to accelerate the implementation as well as to increase the acceptance of solutions. Based on the experience of the CPA pilots, the following good practice activities can be recommended in the field of process organization:

- A *communications plan* should be developed early on in order to inform all relevant participants. Within the Titchwell Marsh and Schouwen-Duiveland cases, communication strategies were established and successfully implemented. A communication plan provides for a structured process, ensuring that all relevant stakeholders have the opportunity to engage with the project. It clarifies key messages for each audience. This involves, for example, newsletters, press contacts, participation in events, targeted meetings, posters, brochures, maps, reports, and even museum expositions.
- *Organizing stakeholder involvement* is essential for the development of a joint vision and raising acceptance of the adaptation process. This was achieved in the CPA pilot projects through a variety of forms, e.g., regional fora and focus groups (Wesermarsch), public drop-in sessions (UK), and bilateral and multilateral meetings, workshops, and events. Special attention should be dedicated to the involvement of the private sector to better utilize local and regional knowledge and their innovative capacity for the climate adaptation process.
- *School projects* can help increase awareness of climate change issues. The involvement of scholars and students in the development of adaptation options in the Schouwen-Duiveland pilot project proved to be successful for creating awareness. Scholars themselves are future stakeholders in their region, and they spread awareness through their networks and parents as well as other stakeholders involved. As part of the pilot project, they developed innovative solution based on new and unexpected views.
- A tool which can contribute to active participation of stakeholders is a *matrix-based decision support* tool. Such a tool has been developed in Sweden and provides a checklist for monitoring complex integrated processes and a methodology to stimulate discussion among stakeholders about crucial items (Andersson-Sköld et al. 2011). It facilitates the identification of potential measures and land use consequences from short- as well as long-term perspectives. It contributes to a more transparent decision-making process, allowing different stakeholders to give weights to various consequences and actions. Alternatively, a *participatory integrative assessment* can be applied following Ahlhorn (2009).
- As mentioned above, climate adaptation can be characterized by a long-term perspective and a low sense of urgency. To overcome this obstacle and accelerate the process, climate adaptation can be *connected to local problems and initiatives*. One of the strongest approaches to achieve commitment for climate adaptation proved to be the connection to current regional problems, projects, and initiatives in which stakeholders are already involved. Examples are flood mitigation programs, initiatives on urban (re-)development, or ecological habitat improvement programs. Beyond this, currently experienced climate impacts (e.g., within the agricultural sector) can function as a good starting point for climate proofing activities.
- Often, regions or countries are known for their expertise in a specific field of action (e.g., Dutch water and dike boards for their innovative sea defense and water management systems). *Cross-national exchange* between climate adaptation projects can transfer knowledge and experiences to other regions.

During the CPA project there have been several exchanges of experience between the different project areas. Project members from different countries acted as so-called Community of Practice, exchanging experiences and information by means of excursions, project meetings, and mutual presentations. These have been valuable in contributing to the solution of pilot project-related problems and served as a catalyst for successful progress.
- Finally, specific attention can be paid to more *strategic local and regional policy making*, which has been accomplished, for example, in Schouwen-Duiveland by getting connected to the municipal strategic vision for 2040.

Adaptation Toolkit: Towards Regional Climate Adaptation

Analyzing the experiences from the CPA project in terms of successfully applied practices and approaches, it appears meaningful to structure the good practice examples in terms of assigning them to the different phases of the *problem-solving cycle*. Thus, a more generic approach for regional climate adaptation in coastal areas can be outlined, as realized as part of the *Adaptation toolkit towards regional climate adaptation* developed with the CPA project (van Oostrom et al. 2011). This will be illustrated by a number of recommendations and specific issues attached to different phases of the problem-solving cycle.

Problem Definition

First of all, regions should be encouraged to undertake regional climate adaptation initiatives. Climate change is an important issue worldwide, and the regional level provides challenging opportunities to link this issue to different sectors and regional land use planning from an integrative perspective. Assuming there is enough awareness among stakeholders, they are able to form a regional alliance (see, e.g., Goltemann and Marengwa 2012) and initiate a climate proofing process. Stakeholders need to be integrated in the climate proofing process from the beginning.

Problem Specification

In most cases it is recommended to undertake a regional climate impact analysis, including the items as listed in the previous section. This analysis should have regard to the abovementioned climate impacts issues that are particular for coastal regions. Stakeholders representing different sectors have to be involved in the regional analysis. Modeling and the development of (long-term) scenarios is needed to understand the range of possible effects, especially at local and regional scales. Therefore, more detailed site-specific information and data is required than what is actually available on global and national scale. Timescales need to be adjusted to planning periods in order to facilitate the development of no-regret (or at least low-regret) adaptation options.

Generation of Solutions

The CPA project showed that pilot projects can generate a large number of possible options to adapt to the identified climate impacts. In order to raise acceptance (in subsequent phases), it is recommended to involve stakeholders also in this phase of the process. CPA itself was a valuable knowledge base for climate proofing activities in other regions. It is recommended that accessible and clustered information platforms on regional, national, and EU levels are created in order to share experience.

It is a challenge to create consistent and comprehensive regional adaptation strategies, especially those involving both physical and socioeconomic actions. Regional and local knowledge and the innovative capacity of the private sector should be harnessed at the earliest opportunity to better ensure the success of solutions chosen.

Choice of the Best Solution

Regional and local administrations must embed climate adaptation within decision-making processes with regard to any plans, policies, and land use programs that might affect the ability of a region to adapt to climate change in the future. It is therefore essential to integrate climate impact assessment into formal processes such as the environmental impact assessment (EIA).

Whether chosen solutions are successful or not depends on the future development of a region. Therefore, before choosing adaptation solutions, decision makers should agree on a common vision for the region, having involved stakeholders and the public. Adaptation solutions that match the vision should have broader acceptance and accelerate the implementation process.

Finally, adaptation strategies should aim to add value. Socioeconomic and environmental benefits should be identified and considered together in order to generate no-regret solutions and should aim for win-win outcomes.

Implementation of the Selected Solution

Climate adaptation can be accelerated by creating so-called windows of opportunity. Thus, climate adaptation should be delivered through ongoing plans and projects in different sectors. Climate adaptation should make use of the climate and weather impacts already experienced by stakeholders. Awareness of today’s climate variability can be very valuable when linking the assessment of possible impacts of climate change in the future to more strategic local and regional policy making. Current weather impacts can be used during the problem specification phase to contribute to analysis and solutions generation.

Evaluation of the Adaptation Process

Climate proofing projects and processes can play an important role in "learning by doing." The results and experiences should be monitored and evaluated and contribute to new projects and initiatives. In this respect it is particularly important to inform the public on experiences and successes. Adaptation is a continuous process, and successful implementation does not mean the future is secure. When further action is needed, at least one stakeholder should take the coordinating role and restart the process.

Recommendations for Regional Scale Climate Adaptation

Some general recommendations can be given in order to optimize the regional climate adaptation process.

- While climate proofing has to be considered as a process rather than a project, a clear *process management* (and process manager) is required, including a *process plan*. The role, position, and responsibilities of different stakeholders, often from different sectors or administration levels, have to be clear and agreed.
- Through all stages of the process, *participation of stakeholders* is a major issue. There are different ways available to facilitate this. Several examples are mentioned in the previous sections (e.g., regional fora, workshops, exhibitions).
- From the beginning of the climate proofing process, *communication and awareness raising* is crucial, especially because climate change is often still perceived as an abstract problem. A communication strategy is a necessity.
- Organization of *cross-regional and cross-national exchange* between climate proofing areas and projects is recommended. This can be very valuable to achieve progress and to improve the quality of analyses, methodologies, solutions, knowledge, and information sharing.

Although most climate adaptation activities are – or will be – undertaken at national, regional, or local level, these can be supported and strengthened by an integrated and coordinated approach at EU level (Com 2009). This is one of the main reasons why the CPA project has been executed under the umbrella of the EU Interreg IVB North Sea Region Program. In connection with the experiences and results from the CPA project, we conclude with a couple of perspectives on European support for regional climate adaptation in coastal areas.

Research

The complexity of climate proofing processes and climate impact analyses requires coordinated and continued research on a number of subjects that are relevant for all regions involved. The CPA project did not generate a research agenda but identified the following issues as illustrative:

- Water and groundwater management under a changing climate must be linked to the framework of national and EU regulations (e.g., Water Framework Directive, Groundwater Directive, Flood Directive, proposed Soil Framework Directive). Although climate change is already implicitly considered, a more explicit consideration is required.
- Management of freshwater supply and (innovative) food production must take care of changing climate conditions. Droughts, waterlogging, and salt intrusion may have severe impacts which might be compensated by innovative drainage systems, fish and seaweed farms, or salt-tolerant agricultural crops (e.g., potatoes).
- Flood risk management has to cope with climate change. The EU Flood Directive has to be connected with climate impacts.
- Climate and socioeconomic scenario development, alignment, and application are necessary to understand and illustrate the potential impacts of climate change. Uncertainties in the science, long-term developments, and working at different temporal and spatial scales make scenario development challenging.
- Governance issues should be applied to regional climate adaptation processes. Stakeholder involvement, cross-sectoral and cross-level cooperation, institutional and planning frameworks, as well as cooperation with the private sector and communication are relevant issues in this respect.

Exchange of Knowledge and Information

Cross-national and cross-regional exchanges between climate proofing pilot areas and projects proved to be very valuable and stimulating in terms of regional climate adaptation. The North Sea Region (NSR) and EU can support these exchanges in many ways, e.g., by the connection to research programs, conferences, and communities of practice and the creation or strengthening of dedicated platforms (e.g., climate-adapt.eea.europa.eu). In addition, the ongoing improvement of information and expert databases or web portals at EU level will contribute to these exchanges (e.g., www.wiser.eu). In this respect it is important that these facilities are promoted, easily accessible, and harmonized as far as necessary. The EU and regional stakeholders should cooperate more to connect regional climate proofing programs to enduring national and international climate research programs.

Policy and Regulations

An important recommendation from the CPA project is that a new systematic tool should be developed which can help “insert” climate adaptation into decision-making. Therefore, a so-called Climate Adaptation Pre-Assessment (CAPrA) should be developed. This should focus on the development and application of climate adaptation criteria within relevant plans and decision-making processes, according to and based on the spirit of a *Strategic Environmental Assessment* (SEA). This is in line with the EU Impact Assessment Guidelines, stating that for any relevant planning option, it should be identified if it affects our ability to adapt to climate change.

European regulations and their translation into national policy frameworks play an important role defining roles and boundaries for climate adaptation at the regional scale. It is therefore important to incorporate climate adaptation strategies in relevant European policies and regulations and to align them with different administration levels in countries and regions. The CPA project has focused less on this issue. Within the different pilots, projects, and analyses, the following relevant directives and policies have been referred to Bird and Habitat Directives (and Natura 2000), Water Framework Directive (and the related Groundwater Directive), EU Flood Directive, Soil Framework Directive (proposed), and the Common Agricultural Policy. Connected with the previously mentioned characteristic climate impacts in coastal areas, in most cases these policies and regulations should be taken into account in climate proofing projects.

Investment Programs

Most of the presented supportive activities can be connected to ongoing EU investment programs regarding research, regional and economic development, or infrastructure. On the other hand, regional authorities and stakeholders should continuously and in a coordinated way specify their needs and present promising strategies in order for relevant EU programs and networks to take them into account.

Finally, a number of specific remarks can be added regarding European support for regional climate adaptation:

- The EU and the NSR play an important role in raising awareness on climate change and climate adaptation. Keeping adaptation on the agenda, creating easy access to information and knowledge and connecting this to all relevant EU-programs will contribute to continued awareness on different stakeholder levels.
- (Inter-)National cooperation between regions can address how to handle differences in regional or local vulnerability to climate change and how to learn from experiences.
- For relevant programs and activities, closer connections with the mitigation domain (regarding CO_2 policy and regulations, renewable energy programs) can possibly strengthen the achievements in the adaptation domain, especially because of the extensive involvement of the EU in mitigation.

Conclusion

Since climate change will affect coastal regions, it is necessary to foster climate (change) adaptation at different spatiotemporal scales. This should mutually be done from an integrated perspective and be embedded in current projects, initiatives, and policies. The regional level is a very appropriate scale in which to link climate adaptation with different sectors and land use planning. The CPA project provided various ideas and experiences to deal with “typical” climate impacts in coastal regions such as higher flood risk, waterlogging, droughts, salinization, ecological disturbance, and freshwater supply for agriculture. Furthermore, the project suggested a more generic approach to guide regional climate adaptation in coastal areas. However, regional climate adaptation is not yet common practice. It is a long and continuous process that requires close coordination between regional, national, and international levels. At EU level, this can be supported by an integrated and coordinated approach regarding research, exchange of knowledge and information, and mainstreaming of policies and regulations and investment programs. At national level, financial and organizational boundary conditions for climate adaptation are set. But at regional level, tailor-made solutions need to be developed and implemented. The tools and approaches presented in this chapter cannot guarantee a successful climate adaptation. Decisions must be made under uncertainty (e.g., with regard to scenario projections), and decisions are made by people often thinking in timescales of elections, investments, or life span of measures rather than of decadal or centennial visions. No-regret solutions and win-win outcomes will not be available in every case. However, the presented tools and approaches can significantly contribute to a successful adaptation process at regional scale since they aim at increasing integration and acceptance of climate change adaptation measures by identifying joint targets and by involving people. In accordance with Integrated Water Resources Management and Integrative Coastal Zone Management, feedback loops will increase the efficiency of adaptation through learning from successes and mistakes and considering information and knowledge gathered meanwhile.

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Himalayan Glaciers Retreat and Implications for Sectoral Climate Adaptation

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Abstract

In the latter half of the twentieth century, an increase in the rate of retreat has been observed in Himalayan glaciers since the advent of industrialization. This chapter attempts to present a critical review and understanding of the recent changes in retreat of selected Himalayan glaciers from climate change and implications for adaptation. The chapter is of great significance to local and regional adaptation planners and local decision makers for communities, ecosystem, and sustainable energy planning. The study discusses the different methods of monitoring changes in Himalayan glaciers; explores scientific evidence and analysis of available data from the glaciers in the Himalayas, from a climate change perspective; and suggests an action plan for future freshwater resource needs downstream.

The data represent fluctuations and varied responses of glaciers of Indian Himalayas towards changes being encountered globally. The longest data series of mass balance available for Shaune Garang glacier does not indicate any generalized trend of mass balance in the region. The analysis of snout retreat in comparison to area of the glacier does not give any information about any relationship between snout fluctuations and area of a glacier. The snout retreat analyzed on regional basis also lack of showing any clear trend of retreat/advance for a particular region. Thus to understand this kind of interrelationship, the influence of microclimatic parameters is required for which there is a lack of data availability. Future efforts in building the resilience of the local community and the ecosystems should take into account a concerted and integrated approach.

Keywords

Himalayan glaciers • Climate change • Water resources • Communities • Power sector • Snout retreat • Glacier mass balance

Introduction

Over the last few decades, changes in climate and local weather conditions have impacted the world's glaciers both in terms of structure and characteristics, reflected in the form of advancement or retreat of glaciers (IPCC 2007; UNEP 2007). The changes in the length, width, area, volume, and mass balance of the glaciers are among the most directly visible signals of global warming, and these changes are the primary reasons for utilizing the glacial observations in climate system monitoring for many years (Haeberli 1990; Wood 1990). These information are useful in areas where time series data on climate (mainly temperature and precipitation) is difficult to get and climate change signals are not yet clear (Yadav et al. 2004; Roy and Balling 2005). Thirty reference glaciers that have been studied in detail since 1975 show an average annual mass loss of 0.58 meters (m) water equivalent in the past decade, which is four times the rate for the period 1976–1985 (UNEP 2007). Hence these unnatural rates of glacial melting can have serious implications on the hydrology of the associated river systems and consequently on the livelihoods of millions of people who are dependent on these rivers and their ecosystems (Stern 2007). Over exploitation of water resources and changes in hydrological cycle could be vital to future developmental strategies of the fertile belt of northern India where agricultural productivity, irrigation, drinking water, and water for industrial use are to a large extent dependent on availability of freshwater resources.

The changing climate is resulting into extremes of temperature and precipitation which impacts negatively by decreasing the seasonal and perennial snow and ice extent (Karl and Trenberth 2003) that further leads to the glacier retreat. Glaciers are retreating in almost every part of the world including in the Alps, Himalayas, Andes, Rockies, Alaska, Africa, and Antarctica (Venteris 1999; Maisch 2000; Barnett et al. 2005; Kaser et al. 2010; Mernild et al. 2011; Venkataraman et al. 2012).

The Himalayas have the highest number of glaciers and snowfields after polar regions (Radic et al. 2013) and is also called as third pole. Most of this snow cover melts away by the end of May (Kulkarni 2010) providing water in their respective catchments. The recent observations through satellite imagery analysis suggest that Himalayan range has about 15,000 glaciers with glacier and ice-covered area of 33,340 km^2 and a total ice reserve of 3,735 km^3 (Bajracharya et al. 2007). In line with the global trends, the Himalayan glaciers and snow cover have also been thinning since the end of the nineteenth century. With significant snout fluctuations, most of the glaciers in the Himalayan mountain ranges have been retreating at accelerated rates in the last three decades, and their rate of retreat is much faster than that of the glaciers in other parts of the world (Parry et al. 2007). In various research studies, it has been found that Himalayan glaciers are retreating in general (Barry 1990; Stone 1992; Shrestha et al. 1999; Barnett et al. 2005; Schmidt and Nüsser 2012) with few exceptions (Bolch et al. 2012). Some more studies are also indicating higher retreating rate of glaciers in the Himalayas (Kulkarni et al. 2005; Kulkarni and Karyakarte 2014) that certainly impacts the future water availability in the associated region. An overall 13 % of glaciated area is lost in the Himalayas in the last 4–5 decades (Kulkarni and Karyakarte 2014). Glaciers of the Himalayas may lose more mass in the coming decades (Chaturvedi et al. 2014). This may affect the streamflow of rivers originating from these glaciers. Ten of the largest rivers in Asia originate from these vast mountain ranges of Hindu Kush Himalayas, flowing trans-boundary to the freshwater demands of more than a billion people living downstream (Kumar et al. 2009). Most of these rivers are perennial due to runoff from glaciers and snow significantly contributing to the flow of these rivers (Immerzeel et al. 2009). Further knowledge of future water availability through the modeling approach is of great help for the policy and planning in the region. Snow and glacier melt model has been used in different parts of the Himalayas using different modeling approach (Kulkarni et al. 2002; Singh and Jain 2003; Singh et al. 2009; Immerzeel et al. 2009; Arora et al. 2010; Ahluwalia et al. 2013).

Snow and glacier melts are one of the most important hydrological processes at these heights and even the minute changes in patterns of precipitation and temperature will seriously affect these hydrological processes. Hence, in comparison to others, these ecosystems are considered as most sensitive towards any likely changes in the climate. The impact on the riverine water system of the Himalayas is manyfold as it supports the requirement for domestic and industrial utilities, irrigation, hydropower generation, and wildlife habitat. Potential of the flow to generate hydropower especially in winter plays a key role in the continuous electricity supply. Also the additional runoff may result in flooding and soil erosion. So a precise estimation for snowmelt runoff in real time is helpful in the planning and execution of mini and micro hydel schemes (Singh et al. 2009).

Several studies, discussed above, are showing negative impact of changing climate on glaciers and snowmelt, which will ultimately affect the water storage capacity and supply in the concerned region. It is interesting to note that some of the studies have reported mass gain in glaciers from different parts of the Himalayan region including Lahaul and Spiti (Vincent et al. 2013) and Karakoram (Hewitt 2005; Bhambri et al. 2012) that raises questions on the understanding of the response of glaciers. A growing body of scientific knowledge solidly indicates that carbon concentrations are changing the global climate and that there would still be significant changes to the global climate even if emissions would drastically reduce. So effects of emissions need to be understood and added onto ongoing glaciological research for having deeper understanding of the climate impacts on critical indicators such as glaciers. This would help in developing regional climate projection models which are more accurate in providing information on future impacts.

The right approach, thus, in addressing these impacts is to have a better scientific understanding through long-term observations and analysis of the interactions of the different components of the mountain ecosystems with their climate, and then utilize this information to formulate effective adaptation and management strategies. There is also a pressing need for disaster management and rehabilitation policies in areas affected by the glacial retreat, particularly focusing on agriculture, meadows, and other livelihood support structures of the local people. The different technologies for the monitoring of snow and glaciers are discussed in next section.

Methods of Monitoring Glaciers

The glacier monitoring is being done with the different objectives, and several techniques are being used as per the requirement and feasibility of the scientific expeditions looking into harsh condition in terms of approach as well as the weather of the Himalayan terrain. Most of the glaciers were monitored at snout to know the recession/advancement in terms of their length and to understand the impact on the discharge patterns. The advent of the remote sensing tool has simplified the glacier monitoring processes for understanding the areal and length changes at larger scale and for longer duration. The only concern is the ground validation of the remotely sensed data and the resolution of the data, which has improved a lot in recent time. With the advancement of the remote sensing technologies, the accuracy became much better and intense monitoring and analysis are being done at a larger scale by different agencies/organizations. The remote sensing imageries have helped in preparing glacier inventory at different interval of time by several agencies.

These studies are still not enough for completely addressing the snow and glacier meltwater in the channels as well as the potential of the freshwater resources in the frozen form. To address the discharge, volume estimation of the snow glacier melt has to be carried out. The volume estimation of glacier melt and accumulation is being done through glacier mass balance for which several technologies are available. Different technologies are being implemented as per the expertise and suitability/feasibility in the glaciated system. The different methods for monitoring of glacier mass balance are listed below.

- Glaciological method
- Hydrological method
- Geodetic method
- Remote sensing method

Glaciological Method

The most common and effective method to assess glacier mass balance is in situ measurement of glacier for ablation and accumulation, known as glaciological method. Mass balance is defined as "the change in the mass of a glacier, or a part of it, over a period of time." The time period for which mass balance is measured is generally as per the hydrological cycle, i.e., end of two consecutive September months. Further, detailed study of accumulation and ablation measurement is done through seasonal measure of glacier mass. The mass balance is mainly influenced by the temperature variation in summer as well as the amount and timing of solid precipitation especially in winter. The mass balance of a glacier in a period of time (t) is calculated by integrating accumulation (c) and ablation (a) over total glacier surface (S).

$$B = \int b\, dS$$

$$b = c + a = \int_{t_0}^{t_i} b\, dt$$

where, $c = \int_{t_0}^{t_i} c\, dt$

$$a = \int_{t_0}^{t_i} a\, dt$$

B = mass balance; S = glacier surface; c = accumulation; a = ablation; t_0 = start of time period; t_i = end of time period; and b = cumulative mass balance over the time period t_0-t_i at a specific point on the glacier.

In situ measurement and direct glaciological methods are synonyms in this measurement process. It involves measurement of ablation and accumulation at the glacier surface by generally using bamboo stakes in ablation area and snow pits and snow probing in accumulation area. The measurements are made at various points and integrated over the entire glacier surface. The possible error in this method is mainly due to network of stakes and pits, the density assumed, as well as the date of measurements and period considered.

Geodetic Method

Cartographic method and topographic method are synonymous to geodetic method. This method refers to determination of glacier mass balance by repeated mapping of glacier surface to estimate the volumetric balance. To convert the measurements of volume change to mass change, information of density of mass loss or gain or assumption on time variation in density is required. The change in elevation with time is generally measured using repeated altimetry, photometry, or ground surveys. The major source of error is assumptions about density of firn and ice required to convert mass change to volume change.

Hydrological Method

This method refers to calculating the mass balance indirectly by solving the water balance equation and calculating the change in water storage in a glacier basin.

$$\mathrm{B} = \mathrm{P} - \mathrm{Q} - \mathrm{E} \pm \Delta\mathrm{S}$$

where B is annual hydrological mass balance, P is precipitation, Q is discharge, E is evaporation or sublimation, and ΔS is variation of storage elements of the catchment area other than glaciers such as groundwater or interception.

This method is comparatively easier but gives information about the whole basin rather the spatial distribution or gradients.

Remote Sensing Method

All earlier methods require presence in field with varying intensities of stay and approach to the glaciers. This becomes difficult in such a harsh terrain and especially if the weather condition is more inclement than the normal. Under the ruthless terrain and weather, earlier methods are difficult to be implemented on many glaciers and especially on larger glaciers. To simplify this process and increase the applicability to a large extent on many glaciers, remote sensing data and tools are being exploited. Based on the field mass balance data on a few glaciers, Kulkarni (1992) was able to introduce an interesting relationship between equilibrium line altitude (ELA), accumulation area ratio (AAR), and mass balance of a glacier. Accumulation area for each glacier usually varies from year to year and mainly depends on the snow line at the end of ablation season. The snow line monitoring has to be done on a weekly basis in the ablation season as per the availability and quality of the remotely sensed data. The WiFS and AWiFS data are being used for snow line monitoring in the Himalaya due to its receptivity of 5 days.

Studies Carried Out in Indian Himalayas

Meltwater Discharge at Different Glaciers of Indian Himalayas

Meltwater discharge is an indirect indicator of glacier health and mass balance. It is also one of the factors needed to calculate the hydrological mass balance of a glacier. It also gives information of fluctuations of glacial meltwater contribution. Apart from knowing the glacier mass balance, the discharge measurements further help modeling the future discharge. The summer (June–September) discharge data available in some part of the Indian Himalayas are presented through Fig. 1.

It is clearly evident from Fig. 1 that the glacial discharge of some of the glaciers in Indian Himalayas are recorded during the melt season (June–September). Long-term monitoring records of discharge contribution are not available to generalize in terms of changes being observed. The discharge data in the graph gives the mixed pattern in different years.

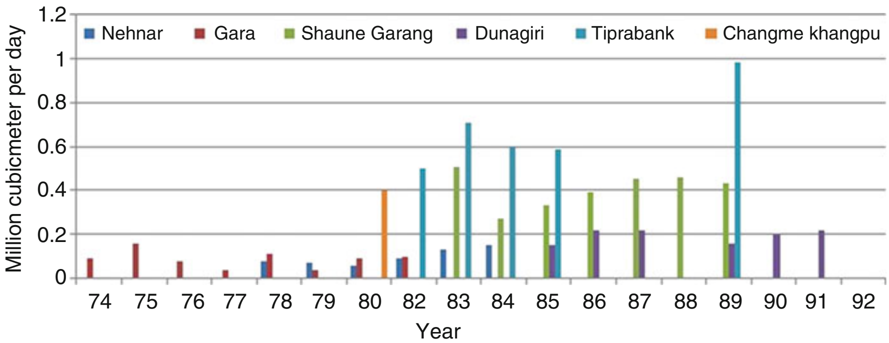

Fig. 1 Average meltwater discharge of some of the glaciers in Indian Himalayas recorded during June–September (Raina 2009)

Mass Balance Studies in Indian Himalayas

The mass balance studies in India dates back to 1974 when Geological Survey of India (GSI) started monitoring of Gara glacier for mass balance over a decade. After that, GSI and other organizations (institutions and universities) took up many more glaciers for mass balance studies. Mass balance studies are carried out using stakes (Wagnon et al. 2007; Dobhal et al. 2008), equilibrium line altitude (ELA), and accumulation area ratio (AAR) methods (Kulkarni 1992; Kulkarni et al. 2004) by satellite laser altimetry (Kääb et al. 2012) or through digital elevation model (DEM) (Berthier et al. 2007). Himalayan glaciers are showing high-mass loss except in Lahaul and Spiti (Vincent et al. 2013) and Karakoram (Hewitt 2005; Bhambri et al. 2012; Kääb et al. 2012). A summary of some of the work in Indian Himalayas carried out on mass balance is presented through Fig. 2 to understand the trend of the mass balance in this part.

The graph shows that in almost three decades of observation of different glaciers in Indian Himalayas, Gara glacier has shown positive mass balance three times and Shaune Garang and Gor Garang glaciers have shown positive mass balance twice. Apart from these few exceptions, all others have shown negative mass balance.

Studies on Glacier Length Changes

Many observations are available in the Indian Himalaya on the changes of position of glacier snout (terminus) since last several decades. It gives information of changes in glacier length but does not give much idea about overall health

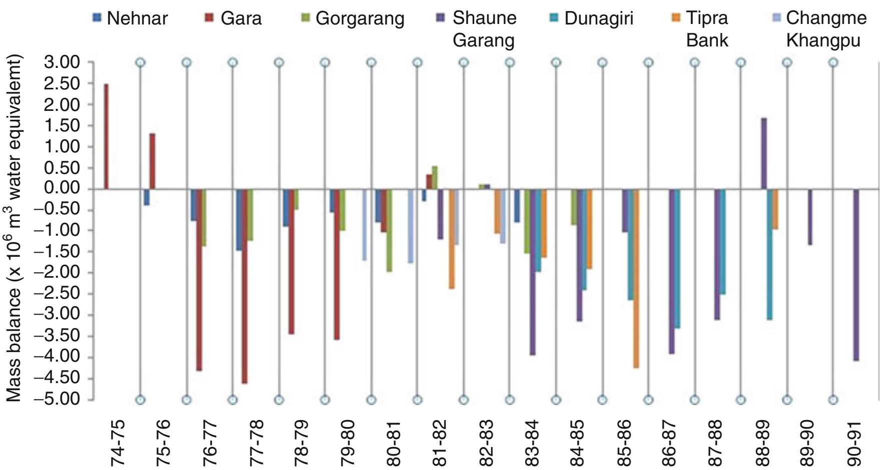

Fig. 2 Mass balance (in million cubic meters water equivalent) of glaciers of Indian Himalayas (Raina 2009)

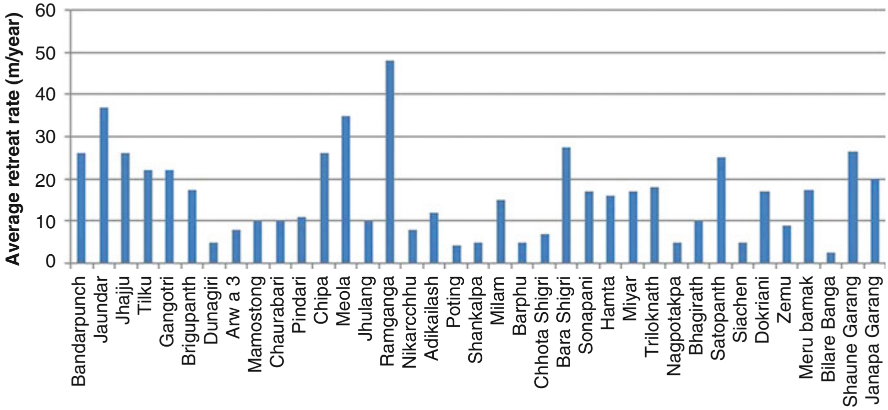

Fig. 3 Average retreat rate of glaciers in Indian Himalayas for which data for more than 20 years were used (Raina 2009; Kulkarni et al. 2005; Kumar et al. 2009; Berthier et al. 2007)

of the glaciers. Some indications of changing climate can be drawn by knowing the change in rate of retreat of the glacier's snout. The response time of glacier to react in form of snout retreat/advance depends on many factors like size of the glacier, temperature variations, and snow precipitation in the region, but the higher retreat rate in the last few decades may be related with the warming trend in the same period. Some of the results of snout retreat from the different publications are shown through Fig. 3. The observations of snout fluctuations for more than 20 years were included to calculate the average retreat/advance of the glaciers. The graph shows that almost all the glaciers are experiencing a retreat more than 5 m per year. Ramganga glacier, Uttarakhand, has been observed to have the highest retreat rate of around 45 m per year.

Issues in Sectoral Adaptation

The threat of glacial melt is likely to have serious implications on several sectors of society and livelihoods exacerbating the stress from existing developmental activities. Sectors which are likely to be affected include water, agriculture, power, and biodiversity.

Water

The supply of freshwater resources is likely to increase as perennial snow and ice volume decrease. Glacial melt runoff in Himalayan glaciers has been highest in the summer months (May–August). The changes in agriculture environments and related water resources may affect crop yields of important crops like wheat and rice in the fertile belt of the Indo-Gangetic Plains. The increased threat of extreme events – floods and droughts leading to glacial lake outburst flood (GLOF) events could threaten mountain communities as well as infrastructure projects downstream.

Agriculture

Changes in freshwater supply in the perennial rivers will affect agriculture productivity. Increases in temperature and water stress are expected to lead to decline in crop yields up to 30 % according to some studies. Changes in phenology and timing of growth due to increased surface temperatures may have a deleterious effect on local vegetation composition. This can have implications for food production and increased competition for land resources.

Biodiversity

The riparian ecosystems in the Himalayan belt comprising deciduous temperate forests are likely to be affected (including shifts in forest boundaries) due to changes in water flows under changing glacial melt. As a result of the rise in average surface temperature, the upward movement of tree line could result in changes in species composition and vegetation types. This will have direct consequences on the range and distribution of high-altitude faunal species including endemic species, some of which occur in a very narrow distributional range. Such species in alpine ecosystems are projected to shift to higher reaches, further shrinking available habitat for their survival.

Power

The perennial rivers of the Himalayan region are an important source for hydropower generation in India. The total hydropower potential of the country has been assessed at about 84,000 MW at 60 % load factor. Of these the Ganga basin has nearly 10,700 MW of hydropower potential. In the past decade, there has been renewed emphasis on exploiting the hydropower potential of such mountain river systems through development of various types of dams for hydro projects. These include run-of-the river hydropower plants which are considered as environmentally friendly by many. However changes in meltwater flows could impact energy security through lack of enough water to run a hydropower plant at full potential. The rapid development of such dams could also cause other indirect effects like environmental impacts of fragile forest ecosystems as well as a livelihood issues like rehabilitation.

Conclusion

There are several methods of monitoring changes in Himalayan glaciers in response to changing climate. Measurement of mass balance is one of the most appropriate methods to have information on overall glacier health and fluctuations. The data represented above clearly shows the fluctuations and varied responses of glaciers of Indian Himalayas towards changes being encountered globally. The short-term increase in discharge contributed by glacier melt and long-term decline in the same are predicted in studies conducted using various models, but the same cannot be concluded from the data discussed. The longest data series of mass balance available for Shaune Garang glacier does not indicate any generalized trend of mass balance in the region.

The analysis of glacial snout and its retreat in comparison to total area of the glacier does not give any information about any relationship between them indicating that there is no any specific impact of size of a glacier on snout retreat. This probably is in agreement with the glacier response time which cannot be concluded on short-term records on glaciers. Distributing the results of snout retreat on regional basis may not show any clear trend of retreat/advance for a particular region. The micro-climate may be playing an important role on the glacier health fluctuation and needs intense study and long data series not only of the hydrological parameters but also of the meteorological parameters to conclude some of the trend very precisely. Hence, one can depict on the basis of these interpretations that despite the area and region, the microclimate of these glaciers is playing the crucial role in determining the changes either in length or mass of glaciers.

Glacial retreat could pose the most far-reaching challenges in the Himalayan region. The importance of Himalayan glaciers for sectoral adaptation efforts in power generation, agriculture, irrigation, food security, biodiversity conservation, river valley ecosystems, etc. has been at the center stage of attention of public and governments as well as the scientists and researchers. For the researchers, the lack of long series data and prevailing uncertainties is of major concern for understanding water resources under the several varying projections of future climate. The dynamics of the monsoon are influenced by Himalayan systems which act as a reservoir to sustaining agriculture, providing freshwater and groundwater recharge, and are home to a unique ecosystem with many endemic species. Adaptation to climate change, therefore, requires not just local action but also trans-boundary cooperative arrangements.

A poor understanding of the glacio-hydrological processes combined with the diversity in topographical relief and climatic conditions within the region makes the hydrological projections speculative about the future water availability, seasonality of runoff patterns, and their impacts on irrigation, hydropower, and hazards.

Future efforts in building the resilience of the local community and the ecosystems should take into account a concerted and integrated approach. There is an urgent need by communities, scientists, and policymakers to take a closer look at the linkages between local impacts, scientific research, policy interventions, and the larger understanding of using resource conservation technologies and practices for promoting societal benefits.

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Linking Social Perception and Risk Analysis to Assess Vulnerability of Coastal Socio-ecological Systems to Climate Change in Atlantic South America

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Abstract

Nowadays no other region on earth is more threatened by natural hazards than coastal areas. However the increasing risk in this area is not just a climate extreme events' result. Coasts are the places with highest concentration of people and values, thus impacts continue to increase as the values of coastal infrastructures continue to grow. Climate change aggravates chronic social vulnerabilities since social groups may be affected differently both by climate change as well as by risk management actions. Relationships between these groups are often characterized by inequality, with different perceptions, response, or adaptation modes to climate hazards. Misperception of these differences often leads to policies that deepen inequities and increase the vulnerability of the weakest groups. Population affected by climatic extreme events increases dramatically resulting in urgent adaptation intervention. We address the interdependence of risk perception and vulnerability of coastal communities and the relevance of ecosystem services for adaptation. We developed a methodology where risk analysis and communities' risk perception are linked through key actions at strategic points of risk assessment: (i) initial interviews with qualified local informants to complete an inventory of ecosystem services, (ii) a social valuation of ecosystem services by local people, and (iii) assessment of stakeholders' social vulnerability. This approach allows a truly socially weighted risk assessment to be validated in three sites: Valle de Itajai (Brazil), Estuary of Lagoa dos Patos (Brazil), and Laguna de Rocha (Uruguay). In this novel approach, risk assessment is forced by social perceptions, thus risk treatment can better contribute to realistic adaptation arrangements to cope with climate forces. Public policies could be improved, recognizing healthy functioning ecosystems as key factor for coastal resilience and well-being.

Keywords

Ecosystem services • Risk assessment • Social perception • Extreme climatic events • Coastal areas

Introduction

In the next decades, the global population affected by coastal flooding and other extreme climatic events will increase dramatically, resulting in a growing need for adaptive interventions (Adger et al. 2005). The increasing impact of climate change is exacerbated because the speed of change is uncertain. The implementation of appropriate actions by the various levels of government is difficult because of the uncertainty of timing and magnitude of climate change and also because of the small window of time of the administrative mandate of governments compared to the time required for the climate change to be perceived. There is a need to implement actions to assist in the development of robust and adaptive management to address uncertain future conditions (IPCC 2007).

Studies have shown that socio-ecological systems do not generally respond to changes, such as those induced by climate change, in a linear manner. Tipping points, described as the achievement of critical thresholds in the system, manifest themselves only after cumulative effects are reached, thereby producing dramatic fast changes (Westley et al. 2011). The capacity of socio-ecological systems to adapt to external disturbances (e.g., flooding) without shifting to different states is known as resilience (i.e., less vulnerable to external forces) and depends on factors such as biological, institutional, and knowledge diversity.

Biodiversity and ecosystem services, especially those associated with wetlands (Boyd and Banzhaf 2007), are natural benefits that people obtain from natural processes (e.g., availability of food and freshwater, protection from erosion, disease regulation, and landscape values) and can be classified as provisional, regulation, support, and cultural services. Ecosystem services are tied to human health, well-being, and ecosystem health and integrity (WHO 2010). The recognition of the key role played by ecosystem services in reducing the effects of climate change is growing worldwide (MEA 2005), although the interdependence is complex and sometimes hidden.

Risk analysis framework is accepted to assist decision-making systematically in doing recommendations as a response to risks and prioritize issues where to focus management efforts (Fig. 1) to address human and natural topics with potential impact (Gimpel et al. 2013), like climate change. The risk analysis approach allows to define links between hazards and ecosystem services (i.e., depicting a pathway effect), which can be used to take the best decision during risk management and risk communication (Lozoya et al. 2011; Cormier et al. 2013). Enormous discrepancies are commonly observed in risk definitions, perceptions, and evaluations, mainly between public opinion and scientific perspectives (Figueiredo 2009).

Understanding social perceptions of climate change risks is critical to motivate public support to promote adequate policies. According to Mastrandrea et al. (2006),

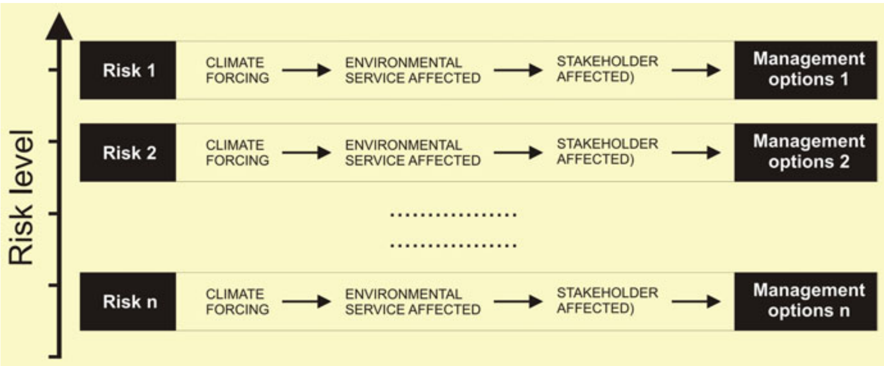

Fig. 1 The role of risk assessment in assisting decision-making to prioritize issues and define management options to cope with climate change. Without a quantitative rank of the risks, the decision where to focus management efforts is unfounded

climate-related risks are commonly perceived by the public as remote, deniable, or manageable, and these misunderstandings must be overcome to motivate support for policy actions (Franck 2009). Risk perception is important because individuals and institutions must be aware and understand climate change as a present threat in order to develop planned adaptation (Burton et al. 2002).

An Interdisciplinary Approach to Risk Assessment

Coastal Areas Within the Anthropocene

The implications of a changing climate are more significant for coastal areas than anywhere else. No other region is more threatened by natural hazards, including winds, storms surges, large waves, hurricanes, and tsunamis (Kron 2013). However, it is not the natural hazard as such that accounts for the consequences of an extreme event. These hazards are natural processes that have always affected the coastal zone. Natural hazards become disasters only if people are killed or injured and/or their possessions damaged or destroyed. Thus, "catastrophes are not only products of chance but also the outcome of the interaction between political, financial, social, technical and natural circumstances" (Kron 2013). Coasts are not just subject to more intense and more frequent natural events, but they are also the places with the highest concentration of people and values. The impacts and associated costs of these natural hazards to humans continue to increase as the amount and values of coastal infrastructures continue to grow (Shepard et al. 2011; Santoro et al. 2013).

Few years ago ca. 3,000 million peoples lived within 200 miles of the sea, which is to say that almost half of our species lives in the coastal zone (i.e., the 10 % of land), bearing densities 2.5 times greater (Tett et al. 2011). This large concentration of population and activities in coastal areas, with its associated effects on the environment, would be part of what a growing number of scientists call a new geological epoch: the *Anthropocene* (Crutzen and Stoermer 2000). Over the past decades, there has been a significant economic growth worldwide. Although uneven and mainly benefiting developed countries, this growth allowed people to access more resources (including natural resources) and thus have more services. While this has contributed to satisfying more needs, current models of growth and development also generated environmental degradation.

This upward trend enhancing general vulnerability makes coastal regions ever riskier. Certainly, the number of natural catastrophes in these areas has been increasing in recent decades (Kron 2013). In this scenario, to achieve a sustainable development (natural, socioeconomic, and cultural) in coastal areas is even more significant. Integrated coastal zone management (ICZM) arises as a strategy that promotes this kind of development, especially after the World Summit on Sustainable Development in 2002, when it incorporates the principles of the ecosystem approach.

Integrated Coastal Zone Management and Risk

ICZM strive for achieving a balance between social, environmental, and economic interest in coastal areas, through an approach based on ecosystem-based management, stakeholders' involvement, and the development of operational tools (Conde et al. 2012). During the last decade, countless countries, governments, and organizations have adopted ICZM as the most suitable policy to effectively address issues and problems in the complex coastal domain. It is seen as the superior course of action to integrate technical, political, and communities' interests and considers the participation by local stakeholder as an elementary component for a successful management (Christie et al. 2005).

As an important component of ICZM planning, the interest in coastal risks analysis and assessment has been growing in the last decade. Risk analysis is internationally recognized as an approach to assist decision-making. It is a systematic way of gathering, evaluating, and disseminating information leading to recommendations in response to an identified risk. It is a tool intended to provide decision makers with an objective, repeatable, and documented assessment of the risks posed by a particular action (Cormier et al. 2013).

Yet risk fields are characterized by a certain lack of clarity on many concepts and principles (Aven 2012). Risk analysis has been broadly defined as including risk assessment, risk characterization, risk communication, risk management, and policy relating to risk (e.g., Society for Risk Analysis). However, to many (e.g., ISO, FLOODsite, UNISDR), risk analysis is part of risk assessment and is defined as "a methodology to determine the risk by combining probabilities and consequences." In turn, risk assessment implies to understand, evaluate, and interpret the perception of risk and societal tolerance and to inform decisions and actions in the risk management process (see Fig. 2).

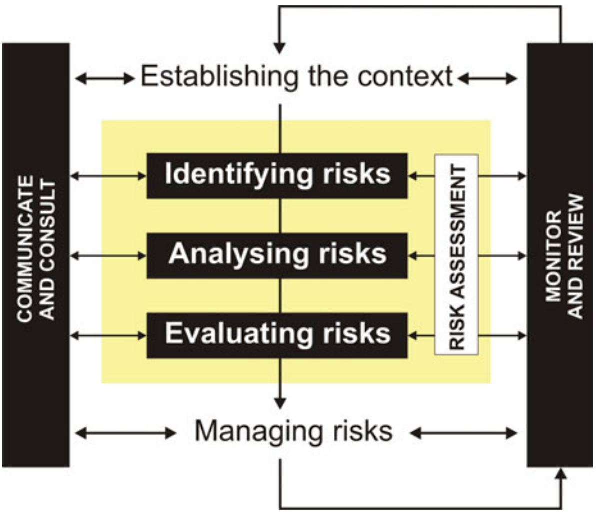

Fig. 2 Key components of the Risk Management Process (Modified from Australian/New Zealand Risk Management Standard)

Given this lack of clarity on many concepts and principles, it is essential, when seeking to carry forward researches on these topics, to establish a priori certain terms and common language in order to be sure of being all talking about the same concepts. This lack of clarity may be even more troubling considering that inter-disciplinary cooperation between physicists, ecologists, economists, and social scientists is essential in risk management processes. Even the use of English is not already a guarantee, since several terms may be interpreted differently in different countries (FLOODsite 2005). Following previous experiences (e.g., FLOODsite 2005; UNISDR 2009; DEFRA 2011), we agreed on a set of key definitions to be used in our project and in this chapter that are presented in the glossary in Table 1.

The set of terms defined in Table 1 present its own particular relationships, which are tentatively depicted in Fig. 3. Key components of the risk assessment method, both addressing the risk on ecosystems and stakeholders derived from climate change hazards, are shown as the central mechanism of an integral risk management process. Ecosystem services are presented as the vital connecting component between end users and ecosystems and human adaptation and ecosystem conservation as the strategies to cope with natural and anthropic hazards.

The Inclusion of Risk Perception in the Integral Analysis of Risk

Risk management calls for integrated processes including all the stakeholders affected (e.g., populations, companies, government, and scientists), joining the main principles of ICZM. Disaster prevention could be truly effective only if all of the stakeholders cooperate in a spirit of partnership (Kron 2013). Communication and consultation are highlighted as relevant at each step of the process (see Fig. 2). However, this dialogue must be bidirectional, stressing consultation and not merely information from managers to stakeholders.

During the last decades, the treatment of public affairs has progressively become more complex. While government agencies maintain significant influence on management, they are just one of multiple actors. In many countries, societies have slowly advanced in the construction of more flexible forms of governance, which are more effective and representative of the interests of diverse social groups. Key factors explaining why new models of governance are emerging include governments' action seeking to implement policies and programs more cost-effective and equitable as well as social demands, which increasingly influence the decision-taking process.

It is extremely important to involve a wide range of stakeholders, particularly scientists with access to detailed knowledge and also those who are most vulnerable and often least consulted. Since climate change affects women and men differently, it is important to consider gender issues such as the unequal power relationships between genders (CEDRA 2012). People's risk perception is based on the expected number of deaths or injuries but also on how well the process is understood, how equitably the danger is distributed, how well individuals can control their exposure, and whether risk is voluntarily assumed. People rank risks based on three major

Table 1 Glossary developed from previous risk management projects (FLOODsite 2005; UNISDR 2009; DEFRA 2011), establishing main key definitions used in this chapter

Concept	Definition
Acceptable risk	The level of potential losses that a society or community considers acceptable given existing social, economic, political, cultural, technical, and environmental conditions
Adaptation	Adjustments in socio-ecological systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities
Consequence	An impact such as economic, social, or environmental damage/ improvement. May be expressed descriptively, by category (e.g., high, medium, low) or quantitatively (e.g., monetary value)
Disaster	Serious disruption of the functioning of a community or a society involving widespread human, material, economic, or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources
Ecosystem services	The benefits that people and communities obtain from ecosystems
Ecosystem service value	Public's net willingness to pay for an ecosystem service (economic definition); relative value given by stakeholders to ecosystem services in relation to their well-being (social definition)
Engagement	Where the public and/or stakeholders are asked to directly and actively take part in decision processes, but a public agency/authority is still responsible for the decision
Exposure	Quantification of the receptors that may be influenced by a hazard (e.g., number of people and their demographics, number and type of properties, etc.)
Hazard	A physical event, phenomenon, or human activity that may lead to harm or cause adverse effects. A hazard does not necessarily lead to harm. Can be natural or human induced
Impact	The effect that a risk would have if it happens
Inherent risk	Risk arising from a specific hazard before any management action has been taken
Qualitative risk assessment	Describes the probability of an outcome in terms that are by their very nature subjective as the assessment typically assigns relative values to assets, risks, controls, and effects
Quantitative risk assessment	A methodology used to organize and analyze scientific information to estimate the likelihood and severity of an outcome. Objective numerical values are calculated for each component gathered during risk analysis
Residual risk	The exposure arising from a specific risk after action has been taken to manage it (making the assumption that the action is effective)
Resilience	Ability of a system, community, or society exposed to hazards to resist, accommodate, absorb to, and recover from the effects of a hazard in a timely and efficient manner, including the preservation of its essential structures and functions
Response	Provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety, and meet the basic needs of the people affected

(*continued*)

Table 1 (continued)

Concept	Definition
Risk	The consequence(s) of hazard(s) being realized and their likelihood/probabilities The combination of the probability of an event and its negative consequences A function of probability, exposure, and vulnerability. Exposure could be incorporated in the assessment of consequences; therefore, it can be considered as having two components: the probability that an event will occur and the impact (or consequences) of the event
Risk analysis	Methodology to determine risk by analyzing and combining probabilities and consequences
Risk assessment	A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that could pose a potential threat or harm to people, property, livelihoods, and the environment on which they depend. Comprise understanding, evaluating, and interpreting the perceptions of risk and societal tolerances of risk to inform decisions and actions in risk management process
Risk management	The complete process of risk analysis, risk assessment, options appraisal, and implementation of risk management measures (i.e., risk treatment)
Risk mitigation	The reduction of the likelihood of harm, by either reduction in the probability of hazard occurring or a reduction in the exposure or vulnerability of the receptors
Risk perception	Subjective appraisal of people (individual or group) on the characteristics and severity of risk, reflecting cultural and personal values, experience, and acquired information
Risk strategy	An organizational approach to risk treatment, well documented and accessible
Risk treatment	Management measures taken to reduce either the probability or the consequences of the hazard or some combination of the two
Stakeholders	Individuals or representatives of groups who are directly or indirectly interested in or affected by an issue or situation
Susceptibility	The propensity of a particular receptor to experience harm. Also a condition that increases the likelihood that an environmental component will be exposed to a particular hazard
Vulnerability	The characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard. Vulnerability is the result of the whole range of economic, social, cultural, institutional, political, and even psychological factors that shape people's lives and create the environment that they live in
Vulnerable groups	Human groups who are prone to show more adverse responses than other groups, given the same exposure

factors: the degree of dreadfulness of the event (e.g., determined by the scale of its effects and the degree to which it affects innocent bystanders), how well the risk is understood (or accepted as fate), and the number of people exposed (Slovic 2000).

It is therefore highly reasonable to search for methodologies that take into account social differences, since social groups may be affected differently both

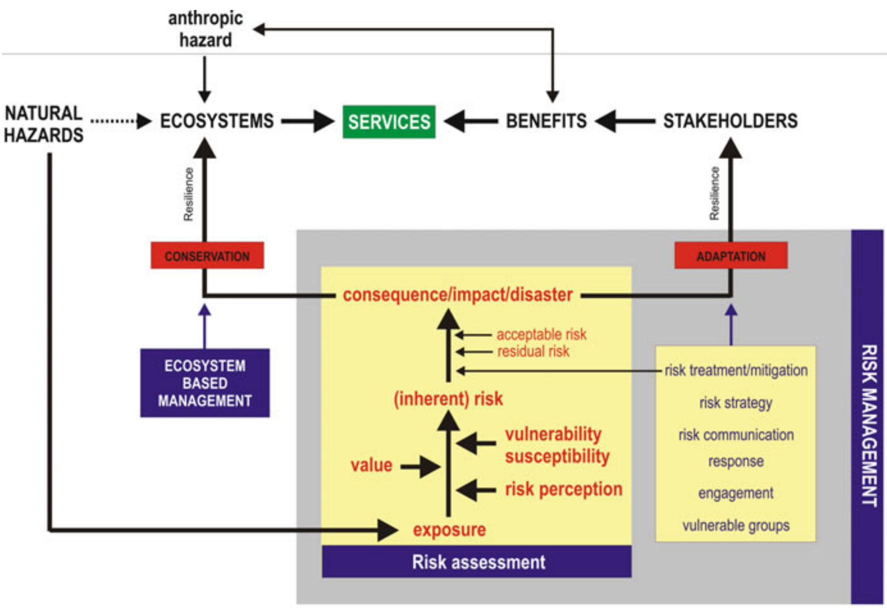

Fig. 3 Flowchart depicting key concepts and terminology related to climate change risk management (and other associated terms), according to the definitions and agreements of the interdisciplinary consortium in charge of this chapter

by climate change and by risk management actions. Identifying different interest groups is relevant because they may also have different perceptions, response, or adaptation modes to climate hazards. Furthermore, the relationships between different social groups are asymmetric and often characterized by inequality. Thus, misperception of these differences often leads to policies and actions that deepen inequities and increase vulnerability of the weakest groups (Fig. 4).

Modified from Shaw et al. (2005), candidate risk perception indicators to these events include, among others, lives threatened during events, impacts on physical and psychological health, and effectiveness of government's and individuals' prevention methods. Although quantification is an essential tool for risk management orientation, the complexity of social/environmental scenarios suggests the necessity integrating the perception of actors and social vulnerability to overcome the merely probabilistic quantification, assuming these are key factors influencing both the final impacts and the adaptive responses.

Ecosystem Services as a Vehicle for Improving an Integral Approach to Risk

During the past two centuries, the dominant paradigm held that natural threats should be managed through better technical protection (Kron 2013). Traditional engineering approaches optimizing for coastal safety are often suboptimal with

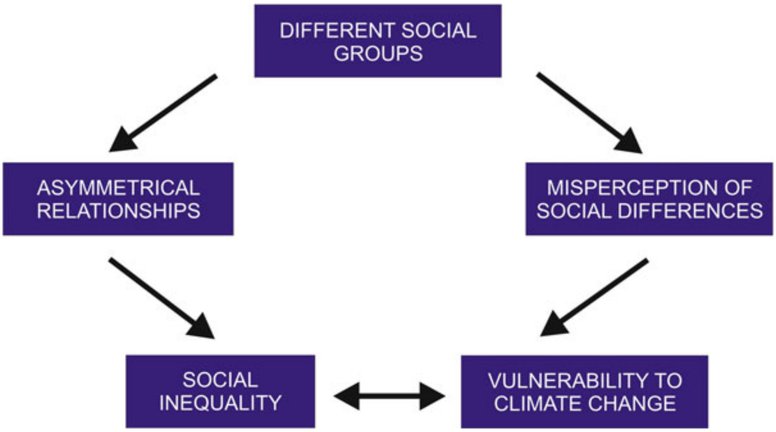

Fig. 4 Asymmetrical relationships among social groups leading to social inequality and how misperception of these differences increases the vulnerability to climate change of the weakest groups, through inadequate policies and actions

respect to other functions and are neither resilient nor sustainable. Historically, coastal protection has been based on hard infrastructures (e.g., walls, jetties, and groins) ignoring and even destroying coastal ecosystems that could provide the necessary protective function.

Natural coastal ecosystems are critical to human societies, providing a diverse range of goods and services that are vital to our well-being, known as ecosystem services (e.g., Costanza et al. 1997; MEA 2005). While scientists and environmentalists have discussed ecosystem services for decades, the UNEP's Millennium Ecosystem Assessment (MEA 2005) marked a major milestone in the historical development of the ecosystem services concept. The MEA distinguished four categories of ecosystem services: provisioning, regulating, cultural, and supporting services, while since then several categorizations have been developed concerning biodiversity conservation, integral environmental assessment, or economic valuation.

The focus on environmental and resources management through the ecosystem services and their link to human well-being proposed by MEA has been pioneering in environmental research. It becomes much clear to identify how changes in ecosystems can affect human welfare. Damage to natural ecosystems will seriously jeopardize their ability to provide these critical goods and services, causing considerable economic and social consequences. One of the most significant contributions of the MEA has been the introduction of ecosystem services in the sustainability's global agenda. The modern concept of ecosystem services has progressed significantly in recent decades, incorporating economic dimensions and providing useful information to decision makers for implementing effective conservation policies which support human well-being and sustainable development (de Groot et al. 2010).

The real importance of coastal services occurred fundamentally after two recent natural disasters: the Indian Ocean tsunami (2004) and hurricane Katrina (2005).

Both scientists and press highlighted the role of marshes as buffers in protecting coastlines, as well as their loss as possible explanation of the disaster. Quickly the protective service eventually provided by coastal marshes against extreme storm surge waves became a contentious issue. Thus the protection of ecosystems and the services they provide can form an important part of climate change mitigation and adaptation strategies (Berry 2013).

Nowadays, ecosystem-based solutions start to be an important component of collaboration between the hazard mitigation and climate change adaptation research communities (Munang et al. 2013). There is a growing interest in identifying where ecosystem-based approaches can fit into the preparation and response to climate change. The importance of ecosystem protection is increasingly recognized (e.g., EU Adaptation Strategy) highlighting the cost-effectiveness and multiple benefits of ecosystem-based strategies that integrating climate and biodiversity policy can help to meet the challenges of a changing climate ensuring the protection of vital ecosystems. However, concerning coastal risk management programs, natural ecosystems and the services they provide to human well-being have just occasionally been considered. The current practice of risk analysis still focuses on damages that can be easily measured in monetary terms. Hence risk assessment mainly deals with damage to assets, while social and environmental consequences are often neglected; this means that risk treatment frequently only manages a part of the total risk (Meyer et al. 2009).

A Regional Approach Linking Social Perception and Risk Analysis to Assess Vulnerability of Coastal Socio-ecological Systems to Climate Change

A Regional Project and Three Pilot Sites

Low-lying coasts in Latin American countries are highly vulnerable to climate variability and extreme climatic events (rain, windstorms and subtropical cyclones, and associated storm surges). The increase of sea level exerts extra vulnerability to low-lying coastal areas already subjected to increasing storm surges and heavy precipitation (Magrin et al. 2007). The coastal area of southern South America is diverse and ecologically stunning, providing a diversity of ecosystems and receiving freshwater from heavily populated watersheds, thus posing substantial risks (Seeliger and Kjerfve 2002). These effects have been shown to cause substantial modifications of the ecosystems' resources, resulting in social impact at diverse scales since communities and institutions have severe difficulties to deal with such changes. These social, economic, and environmental consequences may be synergistically magnified by climate change.

On the Atlantic coast of southern Brazil and eastern Uruguay, low-lying coastal plains formed by sediment accretion, especially during last Holocene period, are susceptible to the effects of flooding and represent a risk to urban areas. Many human groups reveal scarce capacities to cope with further losses of ecosystem services. Although there is an increasing regional recognition of the supporting role played by ecosystem services for human welfare, the perception by communities and managers is still insufficient. Rising sea levels and the increase in frequency and intensity of storms will magnify areas under risk. Coastal vulnerability to climate change has been suggested to generate diverse social and environmental impacts in the region (IPCC 2007).

Impacts at diverse social scales are boosted also because regional communities and institutions still lack capacities and integrated management approaches to deal with climatic long-term changes. Nevertheless, because of the relative homogenous regional culture, opportunities to foster cooperation toward an Atlantic Southern Cone integrated coastal management model are assumed to exist (Menafra et al. 2009). An opportunity to join regional efforts to design and implement management strategies requires identifying lessons learned and sharing previously isolated experiences for strengthening impact mitigation of climate change effects.

To address these topics at a regional, an ongoing research project is specially addressing the interdependence between risk perception and vulnerability of coastal communities to flooding and other extreme events, as well as their perception of the relevance of ecosystem services in reducing the consequences of climate change. This effort is supported by a grant from IDRC-Canada (106,923-001). Universities from Uruguay, Brazil, Canada, and Portugal strengthened an existing consortium addressing integrated coastal management to enable carrying on this research project. The goal of the study is to contribute to develop resilience to climate change in selected coastal wetland ecosystems and communities of the Atlantic Southern Cone of Latin America, especially threatened by extreme climatic events, and to improve recognition of the role of ecosystem services in coping with and adapting to climate change.

Three coastal sites were selected, namely, Valle de Itajai, Santa Catarina; Estuary of Lagoa dos Patos, Rio Grande (in Brazil); and Laguna de Rocha, Rocha (in Uruguay) (Fig. 5). Specific information on relevant socio-ecological features, ecosystem services, and climatic hazards from the three sites are detailed below. Some of the topics now addressed by this consortium have been previously assessed in each of the specific sites, through diverse approaches by coauthors of this chapter. Now, the innovative aim is to develop a regional analysis of these issues, using previous existing information and improving and standardizing the previous experiences, from where to derive lessons learned on a broader scale. Tables 2 and 3 contain comparative listings of major ecosystem services and climatic and anthropic drivers, in the three sites.

Itajai Valley, Santa Catarina (Brazil)

The Itajai Valley is located in the northern portion of Brazil, being drained by the largest river in the state of Santa Catarina, the Itajai River. Floods in the region in the nineteenth century were recognized as a recurring phenomenon. People migration process and occupation on the banks of the rivers turned the situation more complex because of the intense urbanization process. In the last 30 years, countless lives and material losses occurred from major floods (1983, 1984, 2008, and 2011). Society and government efforts with the purpose of seeking,

Fig. 5 Map of the coastal zone of Atlantic South America, showing the three sites where this study was carried out: Valle de Itajai, Santa Catarina; Estuary of Lagoa dos Patos, Rio Grande (in Brazil); and Laguna de Rocha, Rocha (in Uruguay)

diagnosing, planning, and implementing actions and nonstructural actions to mitigate the problems have taken place (e.g., regional economic-ecological zoning strategies, municipal master plans oriented by precautionary principles, National Policy on Climate Change).

In this context lies the city of Itajai, the most important fishing port in Brazil and second largest exporter of containers. The municipality has an area of 289 km^2 and a population of 190,000 inhabitants. It is located in a vast coastal plain in the central portion of the north-central coast of Santa Catarina. Its high urbanization further contributes to economic losses due to flood. The floods of 1983 and 1984 severely affected Itajai, and in 2008 ca. 90 % of the city was flooded. In 2011 the floods affected more than 60 % of the area. To mitigate the existing problems, recent governmental initiatives led to developing models, strategies, and tactics not based on the recognition of local features. There is an urgency of analyzing different low-cost regional planning options, including education, and to propose strategies based on models involving society, governments, and private sector, along a local process of integrated management and governance explicitly recognizing climate change.

Table 2 Listing of ecosystem services in three coastal pilot sites in Brazil and Uruguay

Ecosystem services		
Itajai	Rio Grande	Rocha
Inland artisanal and coastal industrial fisheries	Food supply from industrial and artisanal fisheries and shrimp intense production	Traditional artisanal fisheries and shrimp natural production
Water supply (watershed basins)	Water for domestic, agriculture, and industrial consumption	Water supply for nearby seaside
Riparian services (riparian wetlands taking excess of nutrients and protecting river margins from erosion)	Salt marsh services (taking excess nutrients and protecting the estuarine margins from erosion)	Freshwater marsh and salt marsh services (nursery areas, taking excess nutrients and protecting lagoon margins and coastal front from erosion)
Organic production of the low river and soil formation (supports productive ecosystems like agricultural areas, marshes, and beaches)	Organic production of the estuary and soil formation (supports multiple productive ecosystems like low-energy agricultural areas, marshes, sea grass beds and algal mats, and beaches)	Organic production of the lagoon and soil formation (supports multiple productive ecosystems like extensive cattle grounds, marshes, freshwater macrophyte beds, sea grass beds, and beaches)
Biodiversity (riparian ecosystem and Atlantic rain forest)	Biodiversity (freshwater and brackish wetland and lowlands)	Biodiversity (freshwater and brackish wetland and prairies)
Cultural spiritual and intellectual needs (local people and intensive tourism)	Attractive landscapes suitable for recreation and tourism activities	Astonishing pristine landscape offering recreational, aesthetic, and cultural services

Relevant research done at the Itajai Valley includes contributions on major climatic hazards (Polette et al. 2012), present coastal challenges (Ferreira and Polette 2009), main management tasks (Polette and Vieira 2009), and environmental education (Acauan and Polette 2011).

Estuarine Region of Lagoa dos Patos, Rio Grande (Brazil)

The estuarine region of Lagoa dos Patos, located at the southern Brazilian coast, may be considered as an environmental system with a high ecological, economic, and social importance. Lagoa dos Patos is a coastal system of impressive dimensions. Having an area of 9,913.93 km^2, it is classified as the largest coastal lagoon of the "choked" type (with a restricted connection to the sea) in the globe. The estuarine region, approximately limited by coordinates 52°14′46″ W and 31°41′40″ S and 51°58′24″ W and 32°11′59″ S, encompasses important urban centers of the Brazilian southern shore, such as the cities of Pelotas and Rio Grande, as well as a substantial pool of production, transformation, and business activities. In ecological terms, it may be classified as a typical estuary of a transition system between ocean and continent, thus suffering the influence of processes, sources, and

Table 3 Relevant climatic hazards and anthropic pressures in three coastal pilot sites in Brazil and Uruguay

Climatic hazards and anthropic pressures		
Itajai	Rio Grande	Rocha
El Niño phenomenon (1982/83 and 1997/98) First hurricane ever observed in the South Atlantic demolished over 3,000 houses in southern Brazil	The combination of high tides with the passage of fronts from south can produce meteorological tides that can easily double its heights, producing severe storm surges with strong erosion effects Storm surges can block the large estuary water discharge and produce floods during severe rain periods	Storm surge formation producing coastal impacts Flooding in upstream county city (Rocha city) and coastal villages (La Riviera, Puerto Botes) and cities (La Paloma) Coastal erosion and morphological modification of lagoon's mouth
Unregulated urban growth along the Itajai River, demographic pressure, poverty, and rural migration Low investment in infrastructure and services	Recent population increase due to new port development Lack of adequate urban infrastructure and services A myriad of social and economic activities going on simultaneously	Potential touristic development (in nearby La Paloma city) toward the lagoon's coastal fragile stripe Promotion of urbanization in potentially flooding areas Artificial opening of the lagoon (natural hydrology modification)
Intersectoral uncoordination of leading agencies and stakeholders in the region	Improper integrated management to deal with the complexity of the present situation	Intensive unplanned tourism at the protected area and lagoon Lack of a local management plan and scarce monitoring

controls from both. There is great use, diversity, and density in the water body itself and by the margins of the estuary of Lagoa dos Patos, including urban occupation, port and industrial activities, an important summer resort and tourist activity, as well as environmental protected areas and artisanal and industrial fisheries. These issues are tightly related to impacts by climate change-related events.

Recently, new discoveries of important oil and gas fields concentrated in the exclusive economic zone in the southeast region of Brazil – a deep-ocean, subsalt formation known as pré-sal – have generated a big thrust in the sector related to the exploration, refining, and transportation of those energy sources. Similarly, the new and important phase in Brazilian oil production has significantly stimulated the national shipbuilding sector, with ships for oil and gas exploration and transportation, and the development of port areas to provide logistic support to the endeavor. In the estuarine region of Lagoa dos Patos, where the Port of Rio Grande is located, the installation of an offshore naval construction pool has brought a sizeable enhancement to local economy and may generate considerable environmental impacts on estuarine ecosystems.

Research done at Lagoa dos Patos, relevant for our proposal, includes studies on socio-ecological effects of climate (Janeiro et al. 2008; Leão et al. 2010) and management (Asmus and Tagliani 2009).

Laguna de Rocha, Rocha (Uruguay)

The Atlantic coast of Uruguay, which has recorded the increasing trends in temperature, precipitation, and sea level rise, includes four important coastal lagoons with intermittent connection to the ocean, which belong to one of the largest systems of coastal lagoons on the planet, extending northward to Brazil and southward to Argentina. Most of these coastal lagoons are natural protected areas according to national and international agreements like UNESCO-MaB, the RAMSAR Convention, and others. These highly productive systems sustain important traditional artisanal fisheries, provide relevant ecosystem functions such as reproductive and feeding areas for fish and shrimp of commercial relevance, constitute feeding and resting areas for Nearctic migratory birds, and provide habitat for endemic vertebrate and plants species. Other ecosystem services include hydrological control, soil generation and maintenance, buffering of basin contamination, and aesthetic values for ecotourism.

Laguna de Rocha is the second largest coastal lagoon of Uruguay and presently the most studied aquatic ecosystem in the country. Land use in the basin (which includes the capital city and nearby tourist seaside towns, with ca. 40,000 inhabitants; up to 80,000 in summer) is mainly extensive cattle rising on natural prairies, but forestry with exotic pines and eucalyptus, artificial prairies, and intensive agriculture have increased 5–10 % in the last decade. These towns commonly suffer flooding events. Traditional tourism is increasing around the fragile sandbar area, and environmental impacts, including eutrophication, coastal erosion, and natural habitat degradation, increased threats to endangered species; loss of scenic values, water quality degradation, and alteration of the natural hydrology can be predicted. The sandbar is opened artificially to reduce flooding of adjacent grasslands used for livestock grazing and to permit the entry of important marine larvae, especially commercial shrimp and fishes. Biodiversity and ecosystem services of Laguna de Rocha and its basin are thought to be heavily threatened by climate change.

Relevant research in Laguna de Rocha includes ecosystem services (Nin 2013), effects of climate on ecosystem services (Fanning 2012), and basin management (Rodríguez-Gallego et al. 2012).

Prospective Analysis of Risks

Derived from the information on the most relevant ecosystem services and hazards in each pilot site (Tables 2 and 3), we performed a prospective analysis to tentatively (and nonquantitatively) identify the major risks to climate change (Fig. 6). As seen, in the three sites, the climate hazard that apparently would impose major effects on ecosystem services and stakeholders is flooding, although due to different causes like precipitation, storm surges, and sea level rise, among others. Changes in wind pattern and induced changes in salinity are also indicated as relevant hazards in some of the sites.

LAGUNA DE ROCHA — Risk level ?

	climate stressor	service impacted	stakeholder	adaptation option
$Risk_1$	Changes in wind pattern	Reduction of entrance of fish and shrimp larvae to lagoon Sand bar and hydrology dynamics	Local artisanal fishermen All stakeholders	Sand bar optimal opening according to larval dynamics Zonation and management plan
$Risk_2$	Flooding	Loss of cattle areas	Cattle rangers	Education to show global benefits of flooding frequency
$Risk_3$	Sea level rise and flooding	Loss of areas for urbanization	Tourism sector	Zonation of urbanizable areas according to local scenarios of sea level rise

LAGOA DOS PATOS — Risk level ?

	climate stressor	service impacted	stakeholder	adaptation option
$Risk_1$	Higher frequency of extreme weather events	Navigability of the lagoon channel	Port and industrial sector	Adapt the security por operation protocol
$Risk_2$	Flooding	Safe areas for human occupation	Local communities	Local spatial planning
$Risk_3$	Increase in the precipitation pattern and salinity decrease	Wetland distribution and production	Artisanal fishermen	Adapt fisheries model Marsh construction

VALLE ITAJAI — Risk level ?

	climate stressor	service impacted	stakeholder	adaptation option
$Risk_1$	Flooding	Wetland areas Fisheries Drinking water Recreation and tourism Agriculture &urbanization Harbour areas & industries	Urban population in general Watershed Committee Artisanal/industrial fishermen Tourism sector Harbour sector Industrial sector People living in slums	<u>Structural planning</u> dikes sanitation barriers channels
$Risk_2$	High tide and sea level rise	Loss of cattle areas		<u>Non-structural planning</u> community organization environmental impact assessment indicator system analysis environmental strategic analysis environmental education

Fig. 6 Prospective analysis to identify the most important risks to climate change in three pilot coastal sites along the Southern Cone of Latin America. Without an objective, but socially meaningful, quantification of the risks, the uncertainty of which of them are to be prioritized reduces the effectiveness of the management efforts

Ecosystem services affected include a large and diverse list where the loss of productive areas both for agriculture and fisheries, as well as for urbanization and industrial development, are highlighted, especially in Itajai and Lagoa dos Patos. Only in Laguna de Rocha ecosystem, natural functions are listed as under thread (sandbar dynamics and hydrology) although in Lagoa dos Patos the loss of wetland areas is also emphasized. Stakeholders potentially impacted by these losses are diverse, from traditional fishermen to port industry, including the tourism sector and poor settlements, among others. Optional management practices to be taken include structural and nonstructural actions, as well as coastal zonation, adaptation of fisheries models and operational port protocols, and environmental education.

Nevertheless, this analysis lacks a quantitative approach to enable prioritizing the risks, in order to adequately rank the management options to be adopted. Without objective and socially meaningful risk quantification, the effectiveness of the management efforts is significantly reduced (Dovers et al. 2008). For these reasons and because of the problems arising when risk is analyzed with no support from stakeholders' interests and opinions, the interdisciplinary consortium carrying on the regional project developed a new methodological framework, taking into account these shortcomings, with the aim of adequately linking the approaches of risk analysis and risk perception (see next section).

Methodological Development

The proposed framework consists of several steps, from defining critical ecosystem services to be selected for detailed analysis of risk and perception to finally obtaining a socially prioritized set of risks that can help managers to decide where to focus management efforts for adaptation. For the explanation we will follow the schematic depiction showed in Fig. 7. As seen in the scheme and explained below, there are three entries where social perception feeds the risk

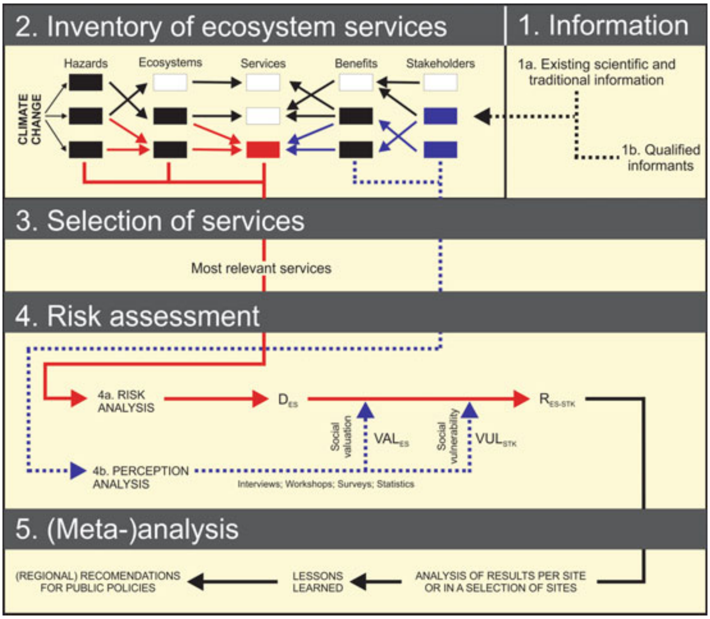

Fig. 7 Methodological proposal for integral risk assessment (*dotted arrows* indicate key points of the framework where social and nonacademic perspectives do feed the risk analysis; *colored boxes* in 2 show an example of how to link one ecosystem service with its climatic hazards, the ecosystems that support that service as well as the related benefits and stakeholders; *red dotted arrows* show the rational pathway from hazards, ecosystems, and services to the risk analysis; *blue dotted arrows* show the rational pathways from stakeholders to the perception analysis) (for abbreviation and other explanations see section "Methodological Development")

analysis: Phase 1 (qualified informants to develop an inventory of ecosystem services), Phases 2–3 (selection of relevant services), and Phase 4 (valuation of services and vulnerability assessment of diverse social groups).

Initially, some agreements must be made on several topics and specific strategies to be followed, by the interdisciplinary consortium. For example, on ecosystem services we decided to follow the classification proposed by Fisher et al. (2009) that differentiates ecosystems (i.e., functions) which provide services, which in turn generate social welfare. To classify ecosystem services, we decided to use a combination of classifications including Fisher et al. (2009), the MEA (2005), and Costanza (2008). Another relevant initial agreement is the definition of the spatial extent of the analysis, which in our case, given we had three different sites, included the provisioning area of the services, as well as the affectation and benefits area. The decision also took into consideration ecological management and operability of the project. These initial definitions are open to any kind of agreement, but it is critical to take place before the further application of the framework.

The first step of the framework consists of the delineation of an inventory of ecosystem services in the working area previously defined (Phase 2 in the scheme of Fig. 8). This must be done as a cooperative effort between scientists and local stakeholders (Phase 1), to obtain the inventory derived from the existing literature (Phase 1b) for the area, as well as from traditional local knowledge. Even if an inventory developed by the academia do already exists for the location under analysis, a series of interviews to qualified informants (Phase 1a) should be carried out to complete it or at least confirm that no relevant information for the local stakeholders is missing. The inventory needs to link climatic forces (hazards) with ecosystems (and ecosystem functions) affected. Then, based on the ecosystem functions, ecosystem services, as well as their associated benefits and stakeholders, can be listed. The potential links between these sequential elements (climate forcing, ecosystems/functions, services, benefits, and stakeholders) can be quantified, especially those critical links between ecosystems/functions and services, using the categorical method proposed by Maynard et al. (2010) based on expert opinion. When the inventory is defined in its wholeness, a decision on which is the critical set of ecosystem services to be addressed in detail can take place (Phase 2 to 3).

It is highly probable that this decision is taken by scientists or managers, but it is relevant that this is done as an artisanal balance taking into consideration not only the scientific opinion by specialized academic staff (e.g., based on climatic scenarios and its potential effect on ecosystems) but also on stakeholders' opinion (i.e., local traditional knowledge), which will obviously prioritize those critical issues that mostly affect their well-being (influenced by their past life experience and the adaption actions they already made, individually or as a community). Seeking for this balance is not an easy task but represents a critical point where a major effort and time must be placed to enable the rest of the framework to be both ecologically and socially relevant. Considering the amount of connections and the number of links between all the sequential elements of the inventory, for the validation of this methodology, one or at least two ecosystem services must be selected, depending on the availability of information and resources at each study site.

a

CASE 1- Decrease in the provision of a single ES provided by ONE ecosystem (E) affected by SEVERAL hazard, which intensities (I_{H1},...,I_{H4}) vary in the different Scenarios (1, 2,..., 6).*						
E	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*
I_{H1}	0,0001	1	0,5	0,004	0,6	0,99
I_{H2}	0,0001	1	0,5	0,7	0,7	0,9
I_{H3}	0,0001	1	0,5	0,03	0,9	
I_{H4}	0,0001	1	0,5			0,8
RC_E	1	1	1	1	1	1
weighted I_H	0,0001	1,0000	=F16/3+F17/3+F18/3			0,8967
D_{ES}	**0,0001**	**1,0000**	**0,5000**	**0,2447**	**0,7333**	**0,8967**

* In these examples, all hazards were considered equal respect to their impacts on each ecosystem (i.e. *k*=1).

b

CASE 2- Decrease in the provision of a single ES provided by SEVERAL ecosystems (E_1, E_2, E_3) affected by SEVERAL hazards, which intensities (I_{H1},...,I_{H5}) vary in the different Scenarios (1,...,4).*										
E	ES	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*		*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
E_1	RC_{E1}	0,1	0,1	0,1	0,1	*IH×RC1*	0,00001	=(F31/2+F32/2)*F30		
	I_{H1}	0,0001	0,9	0,25	1					
	I_{H2}	0,0001	0,1	0,25	1					
E_2	RC_{E2}	0,8	0,8	0,8	0,8	*IH×RC2*	0,00008	0,80000	0,40000	0,00008
	I_{H3}	0,0001	1	0,5	0,0001					
E_3	RC_{E3}	0,1	0,1	0,1	0,1	*IH×RC3*	0,00001	0,05000	0,02500	0,09500
	I_{H4}	0,0001	0,5	0,25	1					
	I_{H5}	0,0001	0,5	0,25	0,9					
	Total RC	1	1	1	1	D_{ES}	**0,00010**	**0,90000**	**0,45000**	**0,19508**

c

CASE 2- Decrease in the provision of a single ES provided by SEVERAL ecosystems (E_1, E_2, E_3) affected by SEVERAL hazards, which intensities (I_{H1},...,I_{H5}) vary in the different Scenarios (1,...,4).*										
E	ES	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*		*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
E_1	RC_{E1}	0,1	0,1	0,1	0,1	*IH×RC1*	0,00001	0,05000	0,02500	0,10000
	I_{H1}	0,0001	0,9	0,25	1					
	I_{H2}	0,0001	0,1	0,25	1					
E_2	RC_{E2}	0,8	0,8	0,8	0,8	*IH×RC2*	0,00008	0,80000	0,40000	0,00008
	I_{H3}	0,0001	1	0,5	0,0001					
E_3	RC_{E3}	0,1	0,1	0,1	0,1	*IH×RC3*	0,00001	0,05000	0,02500	0,09500
	I_{H4}	0,0001	0,5	0,25	1					
	I_{H5}	0,0001	0,5	0,25	0,9					
	Total RC	1	1	1	1	D_{ES}	**0,00010**	**0,90000**	**0,45000**	**0,19508**

* In these examples, all hazards were considered equal respect to their impacts on each ecosystem (i.e. in all cases *k*=1, see general equations).

Fig. 8 Examples of the calculation of the decrease of the ecosystem service provision (D_{ES}) for different hypothetical scenarios (*screen catches* from the supporting information http://www.mcisur.edu.uy/contenidos/riesgo-costero)

After defining these critical ecosystem services potentially affected by climate change, which are also relevant for the local community, the next phase represents the central section of the proposal. Phase 4 corresponds to the risk assessment process, which includes both the risk analysis and the stakeholders' risk perception analysis. Even both analyses have their own methodologies; they are linked through the valuation of the ecosystem services and the inclusion of the stakeholders' vulnerability, as detailed below.

By modifying the methodological development proposed by Lozoya et al. (2011), a risk analysis (Phase 4 in Fig. 7) has to be performed for each ecosystem service and stakeholder (R_{ES-STK}), based on three components: (a) the decrease of the ecosystem service provision (D_{ES}), (b) the value of the service

(VAL_{ES}), and (c) each stakeholder's vulnerability (VUL_{STK}) (see Eq. 1). This calculation gives an estimation of the risk of losing each ecosystem service due to a number of hazards, weighted by the differential vulnerability of each stakeholder associated to the service:

$$R_{ES-STK} = D_{ES} \times VAL_{ES} \times VUL_{STK} \tag{1}$$

It is important to state that some methods included in this phase (e.g., intensity of hazards, valuation, vulnerability, etc.) can be substituted by other specific methods, but it is relevant that these changes are discussed and agreed in advance by the interdisciplinary consortium.

Decrease of Ecosystem Service Provision (D_{ES})

The provision of the ecosystem service of concern will be affected according to the intensities of hazards affecting the ecosystems involved in that provision. Therefore, the decrease of the ecosystem service provision (D_{ES}) is calculated as the summation of the relative contribution of each ecosystem (RC_E) weighted by the intensities of the hazards ($\sum I_H$) affecting each ecosystem (see Eq. 2):

$$D_{ES} = \sum_{E=1}^{E=x} \left(\sum_{H=1}^{H=n} \frac{I_H}{k \times n} \times RC_E \right) \tag{2}$$

where I_H is the intensity of each hazard affecting each ecosystem (E) providing the service, n is the number of hazards affecting each ecosystem, and k is a weighting factor that allows incorporating differences in the relative weights of each hazard, in terms of their effects on each ecosystem.

The relative contribution (RC_E) of each ecosystem to the service provision varies between 0 and 1, being the latter the case where a single ecosystem is responsible for the 100 % of the provided service. RC_E can be estimated based on the methodology proposed by Maynard et al. (2010).

The intensity of each hazard (I_H) affecting the ecosystems can be estimated considering the likelihood of its occurrence (L_H) (e.g., recurrence interval or return period, probability of occurrence, etc.) and its consequences on each ecosystem (CS_E) (e.g., area reduction, functionality reduction, etc.) (see Eq. 3):

$$I_H = L_H \times CS_E \tag{3}$$

Given that several hazards can affect one ecosystem at the same time or space (even producing synergies), their intensities are added in a weighted manner in order to obtain the total intensity affecting each ecosystem (*weighted* I_H).

Finally, if the intensity of hazards increases, the affectation of ecosystem service provision (A_{ES}) will also increase, and therefore the risk of reducing (or even loosing) the ecosystem service will also increase (assuming up to this point that VAL_{ES} and VUL_{STK} are nonzero) (see Eq. 4).

$$R_{ES-STK} = \sum\nolimits_{E=1}^{E=x}\left(\sum\nolimits_{H=1}^{H=n}\frac{I_H}{k \times n} \times RC_E\right) \times VAL_{ES} \times VUL_{STK} \quad (4)$$

In order to illustrate these calculations, two hypothetical cases are presented. Links to the calculations included in each case can be seen and downloaded from http://mcisur.edu.uy/contenidos/Riesgo-Costero/risk-examples.xls. In Case 1, the decrease of the ecosystem service provision (D_{ES}) is calculated for an ecosystem service (ES) that is provided by a single ecosystem (E) (i.e., $RC = 1$) affected by several hazards ($H_1, H_2, \ldots, H_4$). *Weighted* I_H is the total intensity of hazards affecting the ecosystem, and in this case all of them have the same importance (i.e., $k = 1$). In this case the affectation of the ecosystem service provision (A_{ES}) is equal to *weighted IH*, since a single ecosystem is providing the service (i.e., $RC = 1$) (see Fig. 8a below).

In Case 2, the ecosystem service is provided by three ecosystems (E_1, E_2, and E_3), each one of them with different relative contributions (RC_1, RC_2, and RC_3) and affected by different hazards ($H1, H2, \ldots, H5$). As in the first case, for each ecosystem providing the service, the intensities of the hazards affecting were weighted (obtaining the *weighted* I_H, again assuming that all hazards have the same importance, i.e., $k = 1$) and multiplied by the respective relative contribution (see Fig. 8b below). Then, following the main equation presented above, these estimations are added in order to obtain the whole decrease of the ecosystem service provision (D_{ES}) for each scenario (see Fig. 8c below).

Service Valuation (VAL_{ES}) and Stakeholders' Vulnerability (VUL_{STK})
Commonly, an economic valuation of the service is used, based on classical methodology of environmental economics (TEEB 2010; Beaumont et al. 2010). Nevertheless, as part of the methodological development arising from this framework, the interdisciplinary consortium decided to modify this step by replacing the economic valuation by a "social valuation," i.e., based on the relevance of the environmental service for the stakeholders (VAL_{ES}). This will be done through the principles of the analytical hierarchical process (Banai-Kashani 1989), where each interviewed stakeholder (or eventually reaching a consensus in cases of small communities or specific cases of homogeneous opinion) define, on a 1 to 9 scale, how much important are different services, from their viewpoint. Eventually, according to the capacities of the project, an economic valuation can be done in parallel, and results compared or analyzed separately.

A final step in Phase 4 (see Fig. 7) addresses the vulnerability of stakeholders (VUL_{STK}) involved with each service and hazards. It is clear that some groups are to be more vulnerable in losing a specific service by climate drivers. According to Pizarro (2001), the concept of vulnerability seems to be the most appropriate for understanding the transformative impact caused by increased exposure to risks, allowing centering the discussion on social disadvantages, by focusing on the relationships between (i) the physical, financial, human, and social assets available to individuals and groups and (ii) the set of available opportunities delimited by the market, the state, and civil society. Vulnerability analysis emphasizes on quantity, quality, and the diversity of assets (physical, financial, human, and social) that can be mobilized to address environmental dynamics. In this sense, the differential vulnerability among stakeholders will be quantified combining three subindexes that aim to cover all these dimensions:

(a) *Index of unsatisfied basic ne*eds (UBNs): developed by United Nations Economic Commission for Latin America (UNELAC or CEPAL), this index combines population census information on the condition of households (construction material and number of people per room), access to sanitary services, children attending school and education, and economic capacity of household members.
(b) *Index of linkage with the ecosystem service*: based on a set of indicators, this index, developed by this consortium, will measure how connected are actors with the ecosystem service under study, integrating socioeconomic and cultural dimensions (e.g., livelihood, sense of ownership).
(c) *Index of risk perception*: this index, also developed by the consortium, will assess how vulnerable the population perceives itself against the identified hazards. That will be obtained based on indicators providing data on infrastructures, social cohesion, and economic-productive dimensions.

This quantification of the vulnerability will finally allow weighting results of the risk analysis, to be used in the decision process where priorities and issues to be addressed were defined in terms of management, including budget distribution and normative support, among others.

In our case, a further phase (Phase 5 in Fig. 7) of the framework will be pursued, which will allow the regional consortium to derive a series of lessons learned and recommendations based on a meta-analysis of the results from the three cases (Itajai Valley, Lagoa dos Patos estuary, and Laguna de Rocha). These three cases represent a regional gradient which allow for an interesting analysis on how the reduction of wetland areas (i.e., the sequence Itajai → Lagoa dos Patos → Laguna de Rocha) and their associated services, not only due to climate forces but also due to anthropogenic pressures (e.g., urbanization and industrialization), can impact the welfare of local communities and stakeholders and hence reduce their resilience.

Perspectives and Conclusions

The methodology proposed above derives from an interdisciplinary process lasting several months. Experts from several countries, various academic institutions, and a diversity of disciplines developed and adapted a framework that allows prioritizing different risks associated to climate change, according not only to the impacts on ecosystems but also on their services and the human groups that get benefit from them. The framework will now be tested in the three pilot coastal sites along the Southern Cone of Latin America (Laguna de Rocha in Uruguay and Itajai Valley and Lagoa dos Patos estuary in Brazil). Understanding the link between social vulnerability to climate change impacts and the social perception of the risk, as well as of the relevance of coastal ecosystem services, will be valuable to coastal communities, grassroots organizations, governments, and managers at all administrative levels. Regional recommendations, enhancing coastal communities' awareness about the importance of wetland ecosystem services mitigating flooding events, could be derived based on the strength of lessons learned on a regional perspective. This consciousness could lead to the improvement of environmental public policies of the region and involved nations. These local communities affected by climate change will be the major beneficiaries through a better local application of more adequate public policies.

On a more global perspective, in responding to the need for an improved science-policy and science-society interface to manage coastal systems the most sustainable way, the framework presented in this chapter aims to evaluate in a more realistic way the possible effects of climate forces on ecosystems and coastal populations. For it, perception and valuation of local stakeholders are included from the very beginning as a main component of the risks assessment. Community consultation and the need of bottom-up approaches in coastal management have been highlighted since the 1990s as an essential component of the ICZM process. Yet, participation could be seen as more than a democratic right of stakeholders. Cooperation and true engagement is an important condition for successful management, improving equitability and transparency in processes, avoiding the gap between decision makers and affected communities and thereby the failure of planning measures (Jentoft 2000).

This approach is of great importance at present, when climate change aggravates chronic social vulnerabilities, since ecosystem services losses reduce welfare and development opportunities, especially for poorest communities (Malik 2013). On the other hand, considering the relevance of ecosystems and their services to human welfare, as well as its central role in current management and adaptation strategies, it seems essential to place them in the center of the risk management. Thus, this approach may lead to more reliable results in which management decisions can be based on and to improve public policies for better and equitable adaptation strategies, highlighting the central role of healthy ecosystems to cope with climate change.

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Local Determinants of Adaptive Capacity Against the Climatic Impacts in Coastal Bangladesh

Mustafa Saroar and Jayant K. Routray

Contents

Abstract

A growing body of literature came up with suggestion to enhance adaptive capacity of poor and marginalized population to build a resilient society against climatic disasters. Although many earlier qualitative works have indicated the factors that should be addressed to enhance such adaptive capacity, however very scanty of them quantitatively assessed the influences of those factors on various dimensions of people's adaptive capacity. This chapter assesses

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quantitatively the influences of various demographic and socioeconomic, past adaptive behavioral, climate/weather information/knowledge products, and physical environmental (spatial/locational) factors on the adaptive capacity of coastal people against the livelihood insecurity that are caused by hydrometeorological events.

The empirical part of this research was conducted in three villages of Kalapara Upazila (subdistrict) located close to the shoreline of Bay of Bengal in southwest part of Bangladesh. A total of 285 respondents were randomly interviewed using a semi-structured questionnaire in 2009. Respondents were asked to rate their adaptive capacity against 25 impacts that cause their livelihood insecure. The principal component analysis (PCA) technique was employed to identify the major dimensions of livelihood insecurity. Livelihood insecurities are related to (a) severe constraints in agriculture farming and allied activities; (b) severe damage of physical and socioeconomic infrastructures; (c) severe constraints in fishing (mostly offshore) related activities; and (d) severe crisis in freshwater supply and public health risk. How does adaptive capacity against each of these four dimensions of livelihood insecurity differ due to the influence of various factors is assessed by employing multiple analysis of variance (ANOVAs) technique.

The ANOVAs show that among the demographic and socioeconomic factors, sex, education, occupation, farmland holding, membership status (of social institution), and social capitals have the strongest influence on differential adaptive capacity in general. Similarly, among the past adaptive behavioral factors, except the freshwater crisis all other variables, namely, adaptation against flood, rainfall, and salinity intrusion have strong influence in making difference in adaptive capacity. Likewise, almost all climate/weather information/knowledge products have statistically significant influence on various dimensions of adaptive capacity. The policy implication is that while launching any program to enhance the adaptive capacity of coastal people against the threats of hydrometeorological disastrous events on their livelihood security, the identified factors need to be accounted.

Keywords

Adaptive capacity • Climate change • Hydrometeorological disasters • Livelihood insecurity • Coastal Bangladesh

Introduction

This chapter identifies the determinants of adaptive capacity of coastal people in their battle against climate change induced various hydrometeorological events including sea level rise (SLR). Despite considerable uncertainty about the extent and timing of climate change, scientific advances have established a clear link among global warming, climate change, and extreme events (IPCC 2001, 2007). Climate change is basically a gradual change in long-term average conditions, greater variability within the range of normal conditions, and changes in the types of extreme events which are possible or probable (Hare 1991). Common manifestations of climate change is change in global mean temperature, pattern of precipitation, amount of melting of snow and ice, and rising global sea level (Nerem et al. 2006). However, all these have the potential to exacerbate various hydrometeorological disastrous events including cyclonic storms, tidal surges, floods, salinity intrusion, and drought (Wilbanks et al. 2007). The spatial and temporal dimensions of these disastrous events may not be the same across the globe. Therefore, the disastrous events that are more likely for tropics and subtopics may be less likely for arid and semiarid regions and vice versa. Such a variation in climatic events may be felt within a region as well. For example, countries that are located at very lower latitude in the tropics/subtopics may experience noticeably different disastrous events than countries located at more high latitude (IPCC 2001). Although effects of climate change will be felt across the globe, the growing body of literature have warned that small island countries and countries having low-lying deltaic coasts are particularly vulnerable to hydrometeorological disasters (Nicholls et al. 1999; Klein et al. 2001; Karim and Mimura 2008; Tol et al. 2008). Vulnerability will even more increase for countries having low adaptive capacity (Adger et al. 2003; Adger 2006; Stern 2006).

Bangladesh is one of the countries that are susceptible to most of the hydrometeorological disasters, such as floods, cyclones, tidal surges, salinity intrusion, and SLR (Singh et al. 2001; Karim and Mimura 2008; UNDP 2009; GOB 2010; Alvi and Dendir 2011; Pethick and Orford 2013; Ravenscroft et al. 2013; Alam and Rahman 2014; Kulatunga et al. 2014). The vulnerability of this country is attributed to low adaptive capacity and high exposure and sensitivity to these disastrous events (World Bank 2000, Agrawala et al. 2003). It is true that people of Bangladesh have been adapting with natural calamities of various types since time immemorial. They have had accumulated experience of coping and adaptation. However, in the changing context of climate, many of the known hydrometeorological disastrous events may appear very differently than what were earlier. Various climate projection and hydrodynamic models have already warned that Bangladesh may experience more intense cyclonic storms, surges, prolonged flooding, salinity intrusion of perpetual nature, and accelerated SLR (Ali 1999, Singh et al. 2001; Karim and Mimura 2008; GOB 2010; Alvi and Dendir 2011; Pethick and Orford 2013; Ravenscroft et al. 2013; Kulatunga et al. 2014). As Bangladesh is located in a very peculiar geographical setting where the Himalayas is in the north and the Bay of Bengal is in the south, the melting of Himalayan glacier may contribute substantially to exacerbate the flooding situation (Alvi and Dendir 2011; Rahman et al. 2011). In fact, two-third of Bangladesh is located only 5 m above the mean sea level (MSL) and one-fifth of the landmass is within 1 m from the MSL (Islam et al. 1999; Brammer 2014). Past experience shows that decadal developmental gains are ruined by a single episode of massive flood or cyclone (World Bank 2000; GOB 2010). Before reaching the middle of this century, this problem may even get worse primarily because of excessive salinity intrusion in surface, subsurface water table, and in top soil. All these will seriously impact the crop agriculture – the mainstay of the country's economy

(Sarker et al. 2012). Increase in salinity is projected to jeopardize the growth of inland fisheries, horticulture, and forestry as well (Swapan and Gavinb 2011; Islam et al. 2014; Karim et al. 2014). After agriculture, these are the most dominant sources of livelihood in the coastal Bangladesh. Numerous studies already have made strong assertion that if these really happen, a significant number of people with low adaptive capacity will turn out as climate migrants from this fragile coast before the middle of this century (Ali 2006; GOB 2009; Bhuiyan and Dutta 2012; Akter and Mallick 2013; Penning-Rowsell et al. 2013). As any failure to adapt to these impacts of hydrometeorological disasters will cause huge out migration, these massive relocation for a land-scarce country like Bangladesh could only be avoided through enhancing the adaptive capacity of the affected coastal people (Saroar and Routray 2012; Penning-Rowsell et al. 2013).

While enormous literature on adaptive capacity against famine and food vulnerability to natural disasters such as droughts are available in global context, only scanty of literature on adaptive capacity of coastal people against the impacts of hydrometeorological disasters in Bangladesh are found (Adger and Barnett 2009; Adger et al. 2009; Wolf et al. 2010). Often the works of Cannon (2002), Choudhury et al. (2005), Thomalla et al. (2006), Paul and Vogl (2011), Khandker (2012), and Mottaleb et al. (2013) are cited in this regard. While these qualitative studies have unveiled many insightful examples of adaptation against flood, cyclone, drought, even salinity intrusion, those very compelling narratives, however, have the common limitation of analyzing the adaptive capacity qualitatively from a macro perspective. In this regard, notable exception is Saroar and Routray (2012) who have quantitatively assessed the adaptive capacity of coastal people from a micro perspective. However, they have failed to come out from the compartmentalization approach of assessing adaptive capacity. For instance, they have assessed adaptive capacity against major groups of impacts. They have assessed how a person's adaptive capacity differs for different groups of impacts. However, this has little policy significance as it does not empirically tested the causes that make difference in people's adaptive capacity against various hydrometeorological events. Readers may find this chapter as a departure from those qualitative and compartmentalization approaches to identifying the determinants of adaptive capacity at local scale. The practical significance of the finding is that it may help policy makers, planners, and practitioners alike while designing a program of interventions for enhancing people's adaptive capacity.

Adaptive Capacity Against Livelihood Insecurity: Literature Review and the Hypothesis

Livelihood insecurity is often understood as the susceptibility to circumstances of not being able to sustain a livelihood (Alwang et al. 2001; Adger 2006). Therefore, a person's livelihood is considered secure when the person can cope with and recover from stresses and shocks and maintain or enhance capabilities and assets both now and in the future, while not undermining the natural resources base (Scoones 1998). Livelihood security depends on peoples' knowledge and ability to use their assets in such a way that the family can make a living, meet their consumption and economic needs, cope with uncertainties, and respond to new opportunities (de Haan and Zoomers 2005). This means, given the scenarios of changing climate, livelihood security of coastal inhabitants of low-income societies by and large will depend on their ability to adapt to the impacts of climatic disasters as they heavily depend on coastal ecosystem services and agriculture for their livelihood (Wall and Marzall 2006; Allison et al. 2009). Ability to adapt means adaptive capacity which includes some processes or actions, in order to better cope with, manage, or adjust to some changing conditions, stresses, hazards, risks, or opportunities (Fankhauser et al. 1999; Kelly and Adger 2000; Smit and Pilifosova 2001; Brooks et al. 2005; Smit and Wandel 2006). In the changing context of climate, IPCC conceptualizes adaptation as an adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderate harm or exploits beneficial opportunities (McCarthy et al. 2001). Although adaptation is essential, it does not take place automatically. Adaptive capacity largely determines the adaptive potential (Adger et al. 2005; Perry 2007; Norris et al. 2008). Now the question is what motivates individuals to go for anticipatory adaptation against the climatic disasters when there is wide uncertainty?

Although both basic research and empirical studies have identified some of the factors that determine general adaptability of people, none did it quantitatively in the specific context of coastal people. For instance, Kellstedt et al. (2008), and Roser-Renouf and Nisbet (2008) conclude that people adapt when they have the knowledge about the benefit of adaptation and risk of nonadaptive/maladaptive responses (Steel et al. 2005). Their argument is that if the people are well aware about the benefit of adaptive response, they bolster their adaptive capacity. Conversely, people employ their full force to adapt due to fear of loss from no adaptive response. However, other scholars argue that while informedness is necessary but not sufficient. To them, only comprehension of the need for adaptation cannot guarantee any adaptive response in absence of the people's ability to adapt (Smith 1997; Smithers and Smit 1997; Adger et al. 2005). To them, individual's adaptation is largely determined by the material resources that they possess (Blaikie et al. 1994). Drawing on the literature of Maddux and Rogers (1983) personal motivation theory (PMT), some scholars even argue that psychological and behavioral factors also determine people's adaptive capacity. Those who place higher emphasis on disposition of various physical resources argue that a person without these at best can initiate a maladaptive response (Wisner et al. 2004; Pelling and High 2005; Allison et al. 2009). Those who give higher emphasis on psychological matters, they basically point finger to a person's belief about his/her ability to adapt and belief about the effectiveness of such adaptive responses (Maddux and Rogers 1983; Leiserowitz 2006; Semenza et al. 2008; Blennow and Persson, 2009). On the other hand, the proponent of adaptive behavioral factors argues that past experience of adaptive response are invaluable to demonstrate adaptive capacity against a new episode of disastrous event (Patt and Gwata 2002; Grothmann and Patt 2005; Grothmann and Reusswig 2006; Saroar and Routray 2012). The logic here is the utilization of accumulated experience helps them to initiate a new adaptive response. In fact, all arguments have their own merits. Recently, the need for climate information communication appeared as an important determinant of people's adaptive response (Kurita et al. 2006; Collins and Kapucu 2008; Leal Filho 2009; Saroar and Routray 2010). The argument here is timely access to climate/weather information products help people to prepare themselves to adapt. This is vital both for sudden and rapid onset disastrous events such as cyclones, wave surges, tsunamis, and for slow onset or creeping disasters such as desertification or some kinds of floods as well. The bottom line is that timely access to information through various public and private channels help enhancing adaptive capacity. In this respect, another often ignored dimension that some scholars count is the physical environmental or spatial/location factors (Nicholls et al. 1999; Klein et al. 2001; Tol et al. 2008). Some locations due to their geographical/morphological character are more exposed to natural disasters. People who have been living in such marginalized areas are often the disadvantaged groups having very thin adaptive capacity (Adger et al. 2003; Molnar 2010). Although they have very thin physical and financial capital, they often possess solid experience of recurrent adaptation. Apart from these abovementioned factors, various demographic and socioeconomic factors are often counted as cross cutting elements of adaptive capacity (Adger et al. 2003, Moser and Satterthwaite 2009). In fact, adaptive capacity is determined by a bundle of all of the above factors. A right combination of many of these factors can work better in a particular situation, although the same combination may not probe effective while adapting to a very different situation.

The essence derived from various scholarly works cited in the forgoing section leads one to hypothesize that adaptive capacity of coastal people against the threats of various hydrometeorological events on their livelihood security in a multi-hazard-prone area is a function of multiplicity of factors such as demographic and socioeconomic, adaptive behavioral, access to climate/weather information and knowledge products, and physical environmental (spatial/locational) aspects. The general hypothesis is decomposed in the following ways.

Hypothesis 1: Demographic and socioeconomic factors cause differences in adaptive capacity.

Hypothesis 2: Past adaptive behavioral factors cause differences in adaptive capacity.

Hypothesis 3: Access to climate/weather information/knowledge products causes differences in adaptive capacity.

Hypothesis 4: Physical environmental (spatial/locational) factors cause differences in adaptive capacity.

Research Design

Study Area, Survey Procedures, and Respondents

Empirical evidences and many earlier works suggest that “Kalapara Upazila” (subdistrict) of Patuakhali district (an administrative unit below Province/Division) which is roughly above 1 m from the mean sea level (MSL) and located along the Bay of Bengal is worst affected by various hydrometeorological disasters including cyclonic storms, surges, salinity intrusion, tidal floods, and may experience the same in the years to come (Ali 1999; Ali Khan et al. 2000; Singh et al. 2001; Karim and Mimura 2008; Pethick and Orford 2013; Kulatunga et al. 2014). Three villages from three “Union Parishad” (lowest level local government unit) such as Dulasar, Mithaganj, and Nilganj were selected from this subdistrict for the study (See Fig. 1). As a sample unit, individual household was selected. Data and information were collected through administering a semi-structured questionnaire. Randomly selected 285 respondents (usually the head of household) among which 175 males and 110 females were interviewed during January–April, 2009. Although, the original questionnaire was in English, a Bengali version was administered to facilitate the process of data and information collection.

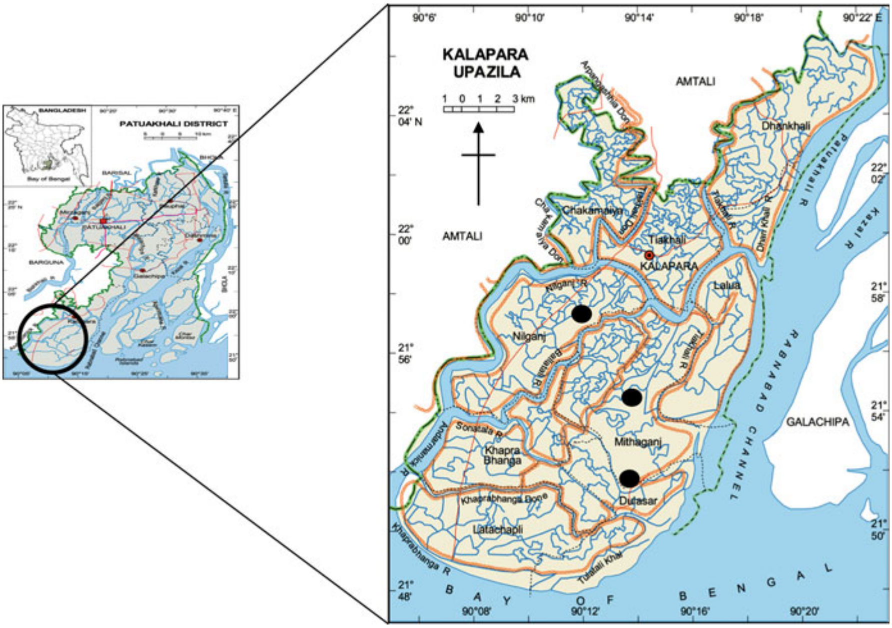

Fig. 1 Study sites (marked with *black circle*) at Dulasar, Mithaganj, and Nilganj *Union Parishad* of Kalapara subdistrict in Bangladesh

The entire study area is crisscrossed by numerous natural cannels/creeks, which are immediately connected to the Bay of Bengal through a network of river system. All the three study sites, which are located roughly within 5–20 km from the shoreline, may experience 10–40 cm inundation due to cyclonic storms, surges, and accelerated SLR before the end of this century (GOB 2005).

The study area is predominantly rural and most land parcels are used for crop agriculture. Cultivation of rice is by far the highest, followed by winter beans, legumes, nuts, and watermelon. Most land parcels are used for wet season rice which is grown during May–November. Peasants and subsistence farmers use family labor, yet agricultural activities generate employment opportunity for a significant number of people during this time. As this time many people go for both freshwater and marine fishing as wel, this brought opportunity for female labors in the farming activities. Usually the day laborers try to earn their maximum during this period to offset the loss of income in unemployed period (winter season). During winter (November to March) people cannot cultivate winter rice because of severe shortage of salt free fresh water. This causes localized seasonal unemployment.

Table 1 shows that the average age of the respondents is 49 years. Nearly half of them belong to senior age group (50 years and above) and almost one-third are in their middle age (35 to below 50). Marginally above 10 % heads of family are within the active age group (below 35 years) who can best utilize their physical labor. Almost 40 % households are comprised of 5 members followed 6-member families (30 %). Almost 60 % of the respondents are illiterate, followed by educational attainment of 5-grade (20 %) and high school graduate (~18 %).

In the traditional society of Bangladesh, the size of landholding determines social position and standing of an individual. Land distribution system is very uneven. Only handful of rich people, locally called *jutders* (landlords) traditionally own most parcels of land. Although one in every four households does not have any cultivable land of their own, some households even have more than 10 acres (~4 hectors) of land. In fact, almost 25 % households do not have any land of their own. Almost half of the households are functionally landless, possessing less than half acre (0.2 hectors) of cultivable land. Yet 8.8 % households possess more than 2.5 acres (~1 hector) of arable land. Even few households possess more than 10 acres of farmland. Therefore, the average farm size is 0.89 acres (0.36 hectors) with a standard deviation of 2.285. This uneven land distribution helps to strengthen a kind of patron–client relationship among the few landlords and the landless/ functionally landless households who cultivate the land of lords accepting often terms and condition unfavorable to them.

The crop agriculture is the most dominant economic activity. Almost one-third of the respondents are engaged in crop agricultural activities. About 20 % families depend on selling labor (day laborer) and almost a similar proportion catch fish (both freshwater and marine) to make a living. Other observed occupations are petty trade, business, transport work, formal job, and various off-farm and on-farm economic activities that combinedly offer livelihood for about 25 % families. However, most of the families possess diversified portfolios of income.

Table 1 Socio-demographic profile of respondents and their families

	Male		Female		Total	
	f	%	f	%	f	%
Age group (year):						
Below 35	19	6.7	12	4.2	31	10.9
35 to below 50	72	25.3	40	14.0	112	29.3
50 and above	84	29.5	58	20.4	142	49.8
Education:						
Nil	101	35.4	70	24.6	171	60.0
Primary level (5th grade)	31	10.9	26	9.1	57	20.
Secondary level (12th grade)	38	13.3	14	4.9	52	18.2
College graduate (14 year plus schooling)	5	1.8	0	0.0	5	1.8
Family size:						
3	16	5.6	8	2.8	24	8.4
4	24	8.4	17	6.0	41	14.4
5	67	23.5	45	15.8	112	39.3
6	52	18.2	30	10.5	82	28.8
7	13	4.6	8	2.8	21	7.4
8	3	1.1	2	0.7	5	1.8
Farmland holding[a]:						
Landless	45	15.8	25	8.8	70	24.6
Functionally landless (<0.50 acre or 0.20 ha)	88	30.9	63	22.1	151	53.0
Peasant farmer (0.50 to <2.5 acres or .20 to 1 ha)	23	8.1	16	5.6	39	13.7
Large farmer (<2.5 acre or 1 ha)	19	6.7	6	2.1	25	8.8

Note: [a]This landholding classification is proposed by BBS (1998) in its Report of the Poverty Monitoring Survey and used to target poor households for poverty-alleviation programs in Bangladesh. It is now widely followed (IFAD 2005).

For most of the occupational groups, flow of income is not smooth throughout the year. The yearly average income of the respondents' families is 141,438 BDT (US$ 2,065; during interview in 2009 the exchange was 68.5 BDT for 1 US$). However, the modal average which is only 65,000 BDT (marginally below US $ 1000) indicates that there are few households who earn much higher than most others.

Selection of Variables and Their Descriptive Statistics

Initially from the review of literature, a total of 23 factors/variables which relate to peoples' adaptive capacity against hydrometeorological disastrous events were selected as explanatory (independent) variables. The dependent variables here are the adaptive capacity of coastal people against various dimensions of livelihood insecurity. Descriptive statistics of these independent variables are presented in Table 2. Following Hardy and Bryman (eds.) (2004), a binary coding procedure is employed for dummy/dichotomous variables. Other variables are measured in their respective SI units. However, as the analysis of variance (ANOVA) technique is

Table 2 Descriptive statistics of explanatory variables used in the research

Original name of the variable and unit of measurement	Variable in abbreviated and dichotomous form	Mean of original variable	Standard deviation
1. Age of the respondent (year)	Age (d): up to 35 is compared with 35 and above	49.34	10.56
2. If sex of the respondent is male? (dummy)	Sex (d): female is compared with male	0.61	0.49
3. Education of the respondent (year of schooling)	Education (d): uneducated is compared with educated	2.86	3.89
4. If agriculture/allied job is the key source of income? (dummy)	Occupation (d): agriculture is compared with non-agriculture	0.76	0.43
5. Total farmland holding (hectare)	Farmland (d): landless is compared with or landholder	0.89	2.29
6. Household's annual income (BDT; 1 BDT = 69.5 US $)	Income (d): up to 60,000 BDT is compared with above 60,000	141438.6	182789.5
7. If member of any social group? (dummy)	Membership (d): no is compared with yes	0.18	0.38
8. Number of times changed settlement since birth due to natural disaster (number)	Change of settlement (number): no is compared with yes	0.20	0.47
9. Distance of settlement from the shoreline (km)	Distance from shoreline (d): up to 10 km is compared with above 10 km	10.00	4.09
10. Distance of safe shelter (e.g., cyclone/flood shelter) (km)	Distance of shelter (d): up to 2 km is compared with or above 2 km	1.73	0.80
11. If safe shelter is easily accessible? (dummy)	Accessibility of shelter (d): no is compared with yes	0.42	0.50
12. If adaptation with flood is recurrent? (dummy)	Flood (d): no is compared with yes	0.75	0.43
13. If adaptation with heavy rainfall is recurrent? (dummy)	Rainfall (d): no is compared with yes	0.63	0.48
14. If adaptation with intrusion of saline water is recurrent? (dummy)	Salinity (d): no is compared with yes	0.53	0.50
15. If adaptation with seasonal scarcity of freshwater or drought is recurrent? (dummy)	Drought (d): no is compared with yes	0.38	0.49
16. If adaptation with cyclone/storm surge is recurrent? (dummy)	Cyclone/surge (d): no is compared with yes	1.00	0.00
17. If always get assistance from relative during income shock? (dummy)	Assistance of relative (d): no is compared with yes	0.42	0.49
18. If always maintain peer network to have weather information? (dummy)	Peer contact (d): no is compared with yes	0.60	0.49

(*continued*)

Table 2 (continued)

Original name of the variable and unit of measurement	Variable in abbreviated and dichotomous form	Mean of original variable	Standard deviation
19. If always use television as a source of weather information? (dummy)	TV (d): no is compared with yes	0.01	0.10
20. If always read newspaper as a source of weather information? (dummy)	Newspaper (d): no is compared with yes	0.04	0.18
21. If always follow radio for weather information? (dummy)	Radio (d): no is compared with yes	0.63	0.48
22. If always adhere weather information? (dummy)	Adherence to information (d): no is compared with yes	0.40	0.49
23. If always maintain contact with officials for assistance? (dummy)	Official contact (d): no is compared with yes	0.20	0.40

intended to use all the independent/explanatory variables (shown in Table 2) are dichotomized based on mean/median values or some logical category as the case applicable. Thus the variable age became younger and elder group; education became uneducated and educated; occupation became agriculture and allied, and others; landholding became landless or landholders; etc. All dichotomized variables are presented alongside the descriptive statistics of original variables in Table 2. However, ultimately the variable – income is not used in the ANOVAs because of the presence of too many outliers (unusually high/low values) at both ends. Likewise, the variable – cyclone is not used because it is appeared as a constant, i.e., 100 % respondents have recurrent exposure to it. Details of the ANOVA procedure are presented later in the respective section.

Result and Discussion

Hydrometeorological Events and Vulnerability of Coastal Livelihood

As the study area is historically exposed to multiple hazards, the respondents are in general familiar with the impacts of cyclones, tidal surges, coastal inundation, salinity intrusion, etc. Although they are not much aware about climate change, global warming or even SLR, they feel that nature has been behaving very differently than what they had seen even one or two decades ago. By and large, respondents have a common perception that recent extreme events are more pronounced than they had been in the past. Furthermore, many of them believe that these extreme events may get even worse in the years to come.

Considering the projected scenario of SLR by the middle of this century, respondents were asked to identify the likely impacts of various hydrometeorological events, including SLR, especially if their farmlands gradually go under half of knee-deep water (20–25 cm) or surge height increases more few meters than they have had in the past. As end-of-the-century projections are large and unstable, so this research has focused on a currently living adult's lifetime as a horizon (for detail arguments, see Allen-Diaz 2009). To facilitate their responses, the respondents were supplied with a list of possible impacts on their livelihood and they were asked to rate their adaptive capacity against each of them in a simple 3-point scale [low to high]. Although the use of 5-point Likert scale is more common, a 3-point simplified scale is preferred to capture the responses of rural illiterate/less educated respondents. Further to assist them, they are suggested to give low adaptive capacity score for impacts that will highly affect their livelihood and vice versa. These simplifications by avoiding complex technical jargons and easing their (ordinary rural people – mostly lay public) understanding of the questions expedited the data collection effort without compromising the quality of data. It is worthy to note that the list of likely impacts of hydrometeorological events on coastal people livelihood security was prepared based on the review of literature having global (see Smith 1997; Middleton 1999; Bosello et al. 2007; Parry et al. 2007; Wilbanks et al. 2007; and Bunce et al. 2010) as well as regional significance with particular reference to the low-lying deltaic coasts of Asia and the Pacific (see Adger et al. 2005; Choudhury et al. 2005; Bi and Parton 2008; GOB 2009).

Table 3 presents the adaptive capacity of people against the impacts of hydro-meteorological events that affect their livelihood security. In more than 50 % cases, the adaptive capacity of people against the impacts of recurrent loss of productive/earning days, freshwater crises, harvest failure and the damage of settlements, food, fuel, and fodder are low. Similarly, a significant proportion of people demonstrate low adaptive capacity against the impacts of low wage rate, limited supply of foodstuffs in the markets, high cost of rebuilding of infrastructure, etc. Although their responses show that about 30 % cases, their adaptive capacity is high against the impacts of risky offshore fishing, increased number of non-fishing days, decreased fish catch per go, and difficulty in fish preservation. These impacts affect the livelihood security of large fishing community (both artisanal and commercial). Therefore, the information directly derived from Table 3 are too broad and do not give any precise grouping of impacts that would affect people's livelihood security by impacting their adaptive capacity.

Livelihood Insecurity and Adaptive Capacity Index

The principal component analysis (PCA) method is employed to bring altogether 25 impact statements under few manageable and distinct categories. Following the Kaiser criterion, the varimax rotation method is used to extract four major groups of impacts against which the coastal people need to have high adaptive capacity to secure their livelihood in the changing context of climate. Although these four groups have explained only 72 % of the variance in people's adaptive capacity against livelihood insecurity, the results are considered statistically valid (i.e., model validity high) because of the following reasons (Field 2005; George and

Table 3 Adaptive capacity of people against the impacts of disastrous events that cause livelihood insecure

	Adaptive capacity[a]		
Impacts of disastrous events	Low % (n)	Medium % (n)	High % (n)
Loss of crop production	48.77 (139)	36.49 (104)	14.74 (42)
Complete harvest failure	51.93 (148)	38.60 (110)	9.47 (27)
Increase cost of agricultural production	44.56 (127)	9.82 (28)	45.61 (130)
Degradation of pastureland	35.44 (101)	16.49 (47)	48.07 (137)
Seasonal shortage of fodder	43.86 (125)	7.37 (21)	48.77 (139)
Difficulty in animal/poultry husbandry	38.95 (111)	30.88 (88)	30.18 (86)
Over bank flow of fishponds/fish farm	3.86 (11)	8.07 (23)	88.07 (251)
Higher risk in offshore fishing	20.00 (57)	14.39 (41)	65.61 (187)
Limited scope of festival and social gathering	35.79 (102)	34.74 (99)	29.47 (84)
Increase in number of non-fishing day	29.12 (83)	5.96 (17)	64.91 (185)
Decrease in fish catch per go	31.93 (91)	3.16 (9)	64.91 (185)
Difficulty in preserving fish	21.75 (62)	18.95 (54)	59.30 (169)
Physical damage of settlement	62.46 (178)	12.28 (35)	25.26 (72)
Damage of stock of food, biomass fuel, and fodder	62.11 (177)	10.53 (30)	27.37 (78)
Cost of maintenance and rebuilding of private infrastructure	44.56 (127)	24.21 (69)	31.23 (89)
Damage of road infrastructure	22.46 (64)	43.16 (123)	34.39 (98)
Damage of social physical infrastructure, e.g., market, school, etc.	38.25 (109)	32.28 (92)	29.47 (84)
Difficulty in physical mobility	18.25 (52)	44.56 (127)	37.19 (106)
Difficulty in carrying goods and commodities	32.28 (92)	39.30 (112)	28.42 (81)
Decrease in number of earning/productive day	61.40 (175)	32.28 (92)	6.32 (18)
Fluctuation/decline in wage rate	48.42 (138)	42.46 (121)	9.12 (26)
Limited supply and stock of foodstuff in the market	42.81 (122)	43.86 (125)	13.33 (38)
Spread of contaminated water	28.42 (81)	54.04 (154)	17.54 (50)
Lack of saline free freshwater for drinking	60.70 (173)	20.00 (57)	19.30 (55)
Prevalence of waterborne diseases	26.32 (75)	54.39 (155)	19.30 (55)

Note: [a]Percentage should be read row-wise; the frequency n is in the parenthesis.

Mallery 2006; Hair et al. 2006). First the value of determinant of correlation matrix was found greater than 0; second, the Kaiser–Meyer–Olkin value for sampling adequacy was greater than 0.60 (i.e., 0.85); third, Bartlett's test of sphericity was significant at $p < 0.0001$; and finally the average communality was >0.500. Loading of these 25 variables (load factors <0.300 are not shown) under four major group are presented in Table 4.

In Table 4, the first group of livelihood insecurity against which people may need to have high adaptive capacity could broadly be labeled as "severe constraints in farming-related activities"; this group includes 10 specific impacts and explains 26 % of the variances in people's adaptive capacity against livelihood insecurity. The second group could be termed as "severe damage of physical and

Table 4 Rotated factor's load matrix of variables which indicates the major groups/dimensions of livelihood insecurity in coastal Bangladesh

	Factors load[a]			
Variables/impact statements	1	2	3	4
Degradation of pastureland	*0.880*			
Seasonal shortage of fodder	*0.860*			
Damage of stock of food, biomass fuel, and fodder	*−0.848*			
Physical damage of settlement	*−0.833*			
Increase in cost of agricultural production	*0.786*		−0.307	
Cost of maintenance/rebuilding of private infrastructure	*−0.728*			
Difficulty in animal/poultry husbandry	*0.676*		−0.321	
Decrease in number of earning/productive day	*−0.675*	−0.303	0.322	
Complete harvest failure	*0.620*	−0.606		
Overbank flow of fishponds/fish farm	*0.444*	0.391		
Damage of road infrastructure		*0.899*		
Difficulty in physical mobility		*0.865*		
Difficulty in carrying goods and commodities		*0.846*		
Damage of social physical infrastructure, e.g., market, school		*0.829*		
Loss of crop production	0.359	*−0.766*		
Fluctuation/decline in wage rate	−0.467	*−0.617*		
Limited supply and stock of foodstuff in the market		*0.614*		
Higher risk in offshore fishing			*0.927*	
Difficulty in preserving fish			*0.904*	
Increase in number of non-fishing day			*0.898*	
Decrease in catch per go			*0.896*	
Spread of contaminated water				*0.912*
Prevalence of waterborne diseases				*0.885*
Lack of saline-free freshwater for drinking	−0.436	−0.369		*0.542*
Limited scope of festival and social gathering				
Variance (%)	***26.11***	***21.75***	***15.63***	***8.47***
Cumulative variance (%)	***26.11***	***47.87***	***63.49***	***71.97***

Note: [a]Extraction method: principal component analysis; rotation method: Varimax with Kaiser normalization (rotation converged in 14 iterations); factor loads less than 0.300 are not shown.

socioeconomic infrastructures," which constitutes seven specific impacts and explains 21.75 % of the variance in people's adaptive capacity against livelihood insecurity. The third group could be named as "severe constraints in fishing (mostly offshore) related activities," which constitutes four specific impacts and explains 15.63 % of the variance. Finally, the fourth group which includes three specific impacts and explains 8.47 % of the variances in people's adaptive capacity against livelihood insecurity is labeled as "freshwater crisis and public health risk."

In general, it was observed that people assigned low adaptive capacity scores against impacts that make them highly vulnerable by heavily affecting their

Table 5 Key statistics of adaptive capacity indices for major four dimensions of livelihood insecurity against the hydrometeorological events

Adaptive capacity index	Min.	Max.	Mean.	SD.	Skewness
Severe constraints in farming-related activities	1.20	2.90	1.91	0.28	−0.43
Severe damage of socioeconomic and physical infrastructures	1.14	2.71	1.88	0.40	0.17
Severe constraints in fishing (mostly offshore) related activities	1.00	3.00	2.38	0.83	−0.75
Severe crisis in freshwater supply and public health risk	1.00	3.00	1.80	0.58	0.44

livelihood security. Now following the methodology of Sullivan (2002) and modifying the formula of Wu et al. (2002), the adaptive capacity index (API) of people against each of these four major groups/dimensions of livelihood insecurity is computed. Therefore, ACI is the arithmetic mean of the adaptive capacity scores against respective impacts, which constitute each of the major four groups/dimensions of livelihood insecurity. Mathematically it can be expressed as

$$I_a = \frac{\sum V_i}{n}.$$

Here, I_a is the ACI (adaptive capacity index) of the respondents against each of the major four dimensions of livelihood insecurity; V_i is the absolute value of response that indicates the level of adaptive capacity against a particular impact that causes livelihood insecure; n is the number of impacts that constitute a major group/dimension among the identified four. The key statistics of each of the four adaptive capacity indices are presented in Table 5.

Each of these four adaptive capacity indices is used as dependent variable in ANOVA (analysis of variance) procedure to identify the factors that cause differences in people's adaptive capacity against livelihood insecurity. These are discussed in some details in the respective sections.

Hypotheses Testing to Identify the Determinants of Adaptive Capacity

Earlier from literature review it was hypothesized that in the changing context of climate, the coastal people's adaptive capacity against livelihood insecurity would be largely determined by demographic and socioeconomic aspects, past adaptive behavioral aspects, access to climate/weather information and knowledge products, and physical environmental (i.e., spatial/locational) aspects. How these four groups of factors influence the respondent's adaptive capacities are determined by employing ANOVA (analysis of variance) technique. These four groups of factors are used as independent variable and each of the four adaptive capacity indices is used as dependent variable in ANOVA procedure. Earlier, to make simple and understandable to nonspecialist readers all independent variables were dichotomized either treating the mid value (average/median) as cutoff point or following the binary coding procedure as the case applicable (for details, see Hardy and Bryman eds. 2004). Therefore, ultimately all the independent variables have two levels (dichotomous variable) which are shown in the respective tables (Tables 2, 7, 8, 9, and 10). Normally for variables having two levels, "independent sample *t* test" procedure is followed. However as multiple (four) independent sample t tests would enhance the probability (about 20 %) of occurrence of type I error, multiple ANOVAs or MANOVA (multivariate analysis of variance) is considered a better statistical technique to employ for this analysis (Field 2005). Partial correlation analysis reveals that there exists very limited correlation (all correlation coefficients are $\leq .40$) among the four dependent variables, i.e., adaptive capacity indices. Therefore, multiple ANOVA technique better suits than MANOVA for these hypotheses testing (Field 2005; Hair et al. 2006). Accordingly, four separate ANOVAs are done instead of doing a single MANOVA. In the following couple of sections, these are presented in some details.

Before employing multiple ANOVAs, the normality of data (dependent variables) is checked which is one of the preconditions of ANOVA application. The result shows that skewness for each dependent variable is less than ± 1 which means data are normal for all the dependent variables (see Table 5). Another precondition of ANOVA is homogeneity of variance (Bryman and Cramer 2001). Levene's test of homogeneity of variance shows that the assumption of homogeneity of variance is not violated because $p > .05$ (Table 6). Therefore multiple (four) ANOVAs are done. Finally, to determine the exact nature of differences in dependent variables (adaptive capacity indices) for each independent variable the parameter estimates was computed in each ANOVA. The post hoc test – univariate pair-wise comparison – was avoided as each independent variable ultimately has two levels. Results of each hypothesis test are presented in Tables 7, 8, 9, and 10.

Hypothesis 1: Demographic and Socioeconomic Factors Determine the Adaptive Capacity Against Livelihood Insecurity

Levene's test statistics shows that assumption of homogeneity of equal variance is not violated as all p values are greater than 0.05 (Table 6); therefore, the models are valid. The models show that demographic and socioeconomic factors determine the adaptive capacity against different groups of livelihood insecurity with varying

Table 6 Levene's test statistics in ANOVA for all four dependent variables

Dependent variable (adaptive capacity index)	F value	Df1.	Df2.	Sig.
Severe constraints in agriculture farming and allied activities	1.26	263	21	0.273
Severe damage of physical and socioeconomic infrastructures	0.575	263	21	0.975
Severe constraints in fishing (mostly offshore) related activities	1.37	263	21	0.200
Severe crisis in freshwater supply and public health risk	0.743	263	21	0.854

proportions. For instance adaptive capacity of 37 % ($R^2 = .37$), respondents against livelihood insecurity that results from severe constraints in agriculture farming and allied activities are determined by demographic and socioeconomic factors such as sex of respondents ($p = .005$), possession of farmland holding ($p = .000$), and membership of social group ($p = .09$) (Table 7). For about 46 % ($R^2 = .46$) respondents, adaptive capacity against livelihood insecurity that results from severe damage of physical and social-economic infrastructure are determined by demographic and socioeconomic factors such as education ($p = .057$), membership of social group ($p = .013$), possession of land holding ($p = .000$), and source of income ($p = .000$) (Table 8). Similarly, for 41 % ($R^2 = .41$) respondents, adaptive capacity against livelihood insecurity that results from severe constraint in fishing-related activities are determined by demographic and socioeconomic factors such as membership of social group ($p = .054$), possession of land holding ($p = .000$), and source of income ($p = .000$) (Table 9). Finally for 32 % ($R^2 = .32$) respondents, adaptive capacity against livelihood insecurity that results from severe crisis of freshwater and public health risk are determined by demographic and socioeconomic factors such as membership of social group ($p = .03$) and access to social capital (i.e., assistance from relatives) (Table 10).

Parameter estimates further reveals that severe constraints in agriculture farming and allied activities affect families having own land 0.22 times more ($p = .000$) and families not belonging to any social groups 0.09 times more ($p = .093$). Conversely, female-headed households are affected 0.08 times less ($p = .005$) than male-headed households. This finding is a bit different than most qualitative research where female-headed families are portrayed as having less adaptive capacity (Cannon 2002; CARE 2003). Why female-headed families are more adaptive against severe constraints in agriculture farming and allied activities is unclear to this author; this requires further exploratory research. Similarly, severe damage of physical and socioeconomic infrastructure affects educated families ($p = .057$) and families not belonging to any social groups ($p = .013$) 0.09 and 0.21 times more, respectively. Landless families are 0.23 times more adaptive against the damages of physical and socioeconomic infrastructures ($p = .000$). Severe constraints in fishing-related activities affect 0.51 and 0.32 times more the families belonging to nonagricultural activities (i.e., fishing) ($p = .000$) and belonging to any social groups ($p = .054$), respectively. Similarly, landless families are 0.45 times less adaptive to the severe constraints in fishing-related activities. Families belonging to any social group ($p = .003$) and families having social capital (e.g., get assistance from relatives) ($p = .000$) are 0.38 and 0.54 times less affected by severe crisis of freshwater and public health risk. Therefore, the hypothesis is not rejected.

Hypothesis 2: Past Adaptive Behavior Determines the Adaptive Capacity Against Livelihood Insecurity

The models show that respondent's past adaptive behavioral factors determine the adaptive capacity against different groups of livelihood insecurity with a varying combinations (Tables 7, 8, 9, and 10). For instance, adaptive capacity against

Table 7 Parameter estimates in ANOVA to determine the influence of various factors on adaptive capacity against livelihood insecurity that results from severe constraints in agriculture farming and allied activities

Independent variables/parameters	B	Std. Error	t	Sig.
Intercept	1.974	0.287	6.889	0.000
Demographic and socioeconomic factors:				
Age (d): up to 35 is compared with 35 and above	−0.067	0.047	−1.426	0.155
Sex (d): female is compared with male	0.083***	0.029	2.859	0.005
Education (d): uneducated is compared with educated	−0.002	0.035	−0.070	0.944
Membership (d): no is compared with yes	−0.099*	0.059	−1.686	0.093
Farmland (d): landless is compared with or landholder	0.224***	0.043	5.192	0.000
Occupation (d): agriculture is compared with non-agriculture	0.048	0.041	1.174	0.241
Assistance of relative (d): no is compared with yes	−0.010	0.037	−0.277	0.782
Adaptive behavioral factors:				
Rainfall (d): no is compared with yes	−0.025	0.034	−0.736	0.463
Flood (d): no is compared with yes	0.030	0.037	0.809	0.419
Drought (d): no is compared with yes	0.018	0.032	0.572	0.568
Salinity (d): no is compared with yes	0.141***	0.034	4.113	0.000
Climate/weather informal factors:				
Radio (d): no is compared with yes	0.008	0.033	0.251	0.802
TV (d): no is compared with yes	−0.365***	0.147	−2.488	0.013
Newspaper (d): no is compared with yes	−.227***	0.090	−2.515	0.012
Peer contact (d): no is compared with yes	−0.050	0.032	−1.588	0.114
Official contact (d): no is compared with yes	0.019	0.054	0.341	0.734
Adherence to information (d): no is compared with yes	−0.036	0.033	−1.091	0.276
Physical environmental factors:				
Distance from shoreline (d): up to 10 km is compared with above 10 km	−0.050	0.032	−1.580	0.115
Distance of shelter (d): up to 2 km is compared with above 2 km	−0.054	0.038	−1.405	0.161
Accessibility of shelter (d): no is compared with yes	−0.024	0.033	−0.720	0.472
Change of settlement (d): no is compared with yes	0.016	0.066	0.246	0.806
F value: 7.34 ($p = 0.000$); $R^2 = 0.37$				

Note: Dependent variable: adaptive capacity against livelihood insecurity that results from severe constraints in agriculture farming and allied activities.
*significant at 0.10; **significant at 0.05; ***significant at 0.01

livelihood insecurity that results from severe constraints in agriculture farming and allied activities are determined by past adaptive behavioral factors such as adaptation against salinity intrusion ($p = .000$). Respondents who have past experience of recurrent adaptation against salinity intrusion are 0.18 times more adaptive against livelihood insecurity that results from severe constraints in agriculture and allied activities (Table 7). Similarly, adaptive capacity against livelihood insecurity that results from severe damage of physical and socioeconomic infrastructures are

Table 8 Parameter estimates in ANOVA to determine the influence of various factors on adaptive capacity against livelihood insecurity that results from severe damage of physical and socioeconomic infrastructures

Independent variables/parameters	B	Std. Error	t	Sig.
Intercept	1.974	0.287	6.889	0.000
Demographic and socioeconomic factors:				
Age (d): up to 35 is compared with 35 and above	0.097	0.061	1.579	0.116
Sex (d): female is compared with male	0.005	0.038	0.137	0.891
Education (d): uneducated is compared with educated	0.087*	0.046	1.915	0.057
Membership (d): no is compared with yes	−0.192***	0.077	−2.498	0.013
Farmland (d): landless is compared with or landholder	0.232***	0.057	4.107	0.000
Occupation (d): agriculture is compared with non-agriculture	−0.421***	0.053	−7.867	0.000
Assistance of relative (d): no is compared with yes	−0.054	0.049	−1.098	0.273
Adaptive behavioral factors:				
Rainfall (d): no is compared with yes	−0.014	0.044	−0.319	0.750
Flood (d): no is compared with yes	0.082*	0.049	1.660	0.098
Drought (d): no is compared with yes	0.033	0.041	0.797	0.426
Salinity (d): no is compared with yes	0.076*	0.045	1.697	0.091
Climate/weather informal factors:				
Radio (d): no is compared with yes	−0.016	0.043	−0.377	0.706
TV (d): no is compared with yes	−0.044	0.192	−0.231	0.818
Newspaper (d): no is compared with yes	−0.075	0.118	−0.635	0.526
Peer contact (d): no is compared with yes	−0.023	0.041	−0.559	0.576
Official contact (d): no is compared with yes	0.024	0.071	0.332	0.740
Adherence to information (d): no is compared with yes	0.063	0.043	1.457	0.146
Physical environmental factors:				
Distance from shoreline (d): up to 10 km is compared with above 10 km	−0.070*	0.042	−1.673	0.096
Distance of shelter (d): up to 2 km is compared with above 2 km	−0.023	0.050	−0.459	0.647
Accessibility of shelter (d): no is compared with yes	0.179***	0.043	4.132	0.000
Change of settlement (d): no is compared with yes	0.024	0.087	0.274	0.784
F value: 10.84 (p = 0.000); R^2 = 0.46				

Note: Dependent variable: adaptive capacity against livelihood insecurity that results from severe damage of physical and socioeconomic infrastructures.
*significant at 0.10; **significant at 0.05; ***significant at 0.01

determined by past adaptive behavioral factors such as adaptation against flooding (p = .098) and salinity intrusion (p = .091). Respondents who have past experience of recurrent adaptation against flooding and salinity intrusion are 0.082 and 0.076 times more adaptive against livelihood insecurity that results from severe

Table 9 Parameter estimates in ANOVA to determine the influence of various factors on adaptive capacity against livelihood insecurity that results from severe constraints in fishing (mostly offshore) related activities

Independent variables/parameters	B	Std. Error	t	Sig.
Intercept	1.992	0.624	3.192	0.002
Demographic and socioeconomic factors:				
Age (d): up to 35 is compared with 35 and above	−0.140	0.134	−1.047	0.296
Sex (d): female is compared with male	0.006	0.083	0.072	0.943
Education (d): uneducated is compared with educated	−0.112	0.099	−1.127	0.261
Membership (d): no is compared with yes	0.324**	0.167	1.936	0.054
Farmland (d): landless is compared with or landholder	−0.450***	0.123	−3.655	0.000
Occupation (d): agriculture is compared with non-agriculture	0.513***	0.116	4.402	0.000
Assistance of relative (d): no is compared with yes	0.115	0.107	1.081	0.281
Adaptive behavioral factors:				
Rainfall (d): no is compared with yes	0.280***	0.096	2.901	0.004
Flood (d): no is compared with yes	−0.220**	0.107	−2.059	0.040
Drought (d): no is compared with yes	−0.170*	0.090	−1.888	0.060
Salinity (d): no is compared with yes	−0.284***	0.098	−2.910	0.004
Climate/weather informal factors:				
Radio (d): no is compared with yes	0.144	0.093	1.546	0.123
TV (d): no is compared with yes	0.051	0.419	0.121	0.903
Newspaper (d): no is compared with yes	0.164	0.258	0.637	0.524
Peer contact (d): no is compared with yes	0.029	0.090	0.321	0.749
Official contact (d): no is compared with yes	−0.088	0.155	−0.564	0.573
Adherence to information (d): no is compared with yes	0.162*	0.094	1.722	0.086
Physical environmental factors:				
Distance from shoreline (d): up to 10 km is compared with above 10 km	−0.139	0.091	−1.535	0.126
Distance of shelter (d): up to 2 km is compared with above 2 km	0.187*	0.109	1.709	0.089
Accessibility of shelter (d): no is compared with yes	0.051	0.094	0.546	0.586
Change of settlement (d): no is compared with yes	−0.044	0.189	−0.231	0.818
F value: 8.85 ($p = 0.000$); $R^2 = 0.41$				

Note: Dependent variable: adaptive capacity against livelihood insecurity that results from severe constraints in fishing (mostly offshore) related activities.
*significant at 0.10; **significant at 0.05; ***significant at 0.01

damages of physical and socioeconomic infrastructures (Table 8). Adaptive capacity against livelihood insecurity that results from severe constraints in fishing-related activities are determined by past adaptive behavioral factors such as adaptation against rainfall ($p = .004$), flooding ($p = .04$), drought ($p = .06$), and

Table 10 Parameter estimates in ANOVA to determine the influence of various factors on adaptive capacity against livelihood insecurity that results from severe crisis in freshwater supply and public health risk

Independent variables/parameters	B	Std. Error	t	Sig.
Intercept	0.977	0.475	2.056	0.041
Demographic and socioeconomic factors:				
Age (d): up to 35 is compared with 35 and above	0.099	0.102	0.971	0.332
Sex (d): female is compared with male	0.084	0.063	1.328	0.185
Education (d): uneducated is compared with educated	−0.120	0.076	−1.592	0.113
Membership (d): no is compared with yes	0.384***	0.127	3.012	0.003
Farmland (d): landless is compared with or landholder	−0.052	0.094	−0.556	0.579
Occupation (d): agriculture is compared with non-agriculture	0.138	0.089	1.557	0.121
Assistance of relative (d): no is compared with yes	0.538***	0.081	6.620	0.000
Adaptive behavioral factors:				
Rainfall (d): no is compared with yes	0.184***	0.073	2.503	0.013
Flood (d): no is compared with yes	0.077	0.081	0.941	0.347
Drought (d): no is compared with yes	−0.012	0.069	−0.180	0.858
Salinity (d): no is compared with yes	0.007	0.074	0.092	0.927
Climate/weather informal factors:				
Radio (d): no is compared with yes	0.059	0.071	0.826	0.409
TV (d): no is compared with yes	−0.062	0.319	−0.193	0.847
Newspaper (d): no is compared with yes	0.354*	0.196	1.803	0.072
Peer contact (d): no is compared with yes	0.002	0.069	0.029	0.977
Official contact (d): no is compared with yes	−0.215*	0.118	−1.816	0.070
Adherence to information (d): no is compared with yes	−0.014	0.071	−0.195	0.846
Physical environmental factors:				
Distance from shoreline (d): up to 10 km is compared with above 10 km	0.032	0.069	0.463	0.644
Distance of shelter (d): up to 2 km is compared with above 2 km	0.140*	0.083	1.685	0.093
Accessibility of shelter (d): no is compared with yes	−0.097	0.072	−1.360	0.175
Change of settlement (d): no is compared with yes	0.101	0.144	0.699	0.485
F value: 5.77 ($p = 0.000$); $R^2 = 0.32$				

Note: Dependent variable: adaptive capacity against livelihood insecurity that results from severe crisis in freshwater supply and public health risk.
*significant at 0.10; **significant at 0.05; ***significant at 0.01

salinity intrusion ($p = .004$). Respondents who have past experience of recurrent adaptation against flooding, drought, and salinity intrusion are 0.22, 0.17, and 0.28 times more adaptive against livelihood insecurity that results from severe constraints in fishing-related activities (Table 9). However, it is unclear why people having recurrent experience of adaptation against rainfall are less adaptive to severe constraints in fishing-related activities. Finally, adaptive capacity against drought (e.g., freshwater crisis) and public health risk are determined by adaptive behavioral factors such as torrential rainfall ($p = .013$). Respondents having recurrent experience of adapting to torrential rainfall are 0.184 times more impacted by freshwater crisis and public health risk (Table 10). Therefore, the hypothesis is not rejected.

Hypothesis 3: Access to Climate/Weather Information and Knowledge Products Determines Adaptive Capacity Against Livelihood Insecurity

The models show that respondent's use of climate/weather information and knowledge products determines the adaptive capacity against different groups of livelihood insecurity with varying combinations (Tables 7, 8, 9, and 10). For instance, adaptive capacity against livelihood insecurity that results from severe constraints in agriculture farming and allied activities are determined by respondent's use of climate/weather information and knowledge products such as television ($p = .013$) and newspaper ($p = .012$). Respondents who use television and newspaper on a regular basis as a source of climate/weather information and knowledge products are 0.37 and 0.23 times more adaptive against livelihood insecurity that results from severe constraints in agriculture and allied activities (Table 7). Similarly, adaptive capacity against livelihood insecurity that results from severe constraints in fishing-related activities are determined by respondent's adherence to climate/weather information and knowledge products ($p = .086$). For instance, respondents who always try to follow the climate/weather information and knowledge products are 0.16 times more likely to be adaptive to severe constraints in fishing-related activities (Table 9). Finally, adaptive capacity against livelihood insecurity that results from severe crisis of freshwater and public health risk are determined by respondents use of climate/weather information and knowledge products such as newspaper ($p = .072$) and official sources ($p = .070$). Respondents who use newspaper and official sources (by contacting local officials) on a regular basis are 0.35 and 0.21 times more adaptive against livelihood insecurity that results from severe crisis in freshwater and public health risk (Table 10). However, uses of climate/weather information and knowledge products do not significantly influence the respondent's adaptive capacity against livelihood insecurity that results from severe damage of physical and socioeconomic infrastructures (Table 8).

To all surprise, it has been observed that no significant differences in adaptive capacities are observed among frequent radio users and nonusers. This finding does not confirm many other findings such as the ones of Kurita et al. (2006), Collins and Kapucu (2008). This research lacks in sufficient empirical evidences to substantiate this unusual finding. Further exploratory research may bring out the latent causes. Similarly, contrary to general expectation it is found that adherence to climate information make only little differences in adaptive capacity of the respondents. Those who always follow weather information are rather worse off while adapting against loss of employment in offshore activities. It is probably because, those who care about weather information hardly go out for off shore/deep sea fishing; therefore, they loss too many earning days throughout the rainy season (June to October) when most of the gusty wind and cyclonic events take place. Finally it can be argued that despite very casual influence of some of the climate/ weather information sources, by and large access to climate/weather information and knowledge products cause differences in respondents' adaptive capacity against the impacts of hydrometeorological events on their livelihood security. Thus, the hypothesis is not rejected.

Hypothesis 4: Spatial and Locational (i.e., Physical Environmental) Factors Determine the Adaptive Capacity Against Livelihood Insecurity The models show that physical environmental factors determine the adaptive capacity against different groups of livelihood insecurity with varying combinations (Tables 7, 8, 9, and 10). For instance, adaptive capacity against livelihood insecurity that results from severe damage of physical and socioeconomic infrastructures are determined by physical environmental factors, such as distance from the shoreline ($p = .096$) and access to safe shelters ($p = .000$). Respondents who have been living within 10 km from shoreline are .07 times less adaptive to severe damage of physical and socioeconomic infrastructures than people who have been living more than 10 km away from the shoreline. Similarly, respondents who have good accessibility to safe shelters are 0.18 times less likely to be affected by severe damage of physical and socioeconomic infrastructures (Table 8).

Similarly, adaptive capacity against livelihood insecurity that results from severe constraints in fishing-related activities are determined by physical environmental factors such as distance of safe shelters from home ($p = .089$). Respondents who have claimed that the nearest safe shelter is less than 2 km away are 0.19 times more likely to be adaptive to livelihood insecurity that results from severe constraints in fishing-related activities (Table 9). Finally, adaptive capacity against livelihood insecurity that results from severe crisis of freshwater and public health risk are determined by physical environmental factors, such as distance of safe shelters from home ($p = .093$). Respondents who have claimed that the nearest safe shelter is less than 2 km away are 0.14 times more likely to be adaptive to livelihood insecurity that results from severe crisis of freshwater and public health risk (Table 10). It is probably because in most cases construction of safe shelters are accompanied by construction of freshwater ponds for use in emergencies as well as in normal time. However, physical environmental factors do not have statistically significant influence on respondent's adaptive capacity against livelihood insecurity that results from severe constraints in agricultural farming and allied activities. Therefore, the hypothesis is not rejected.

Overall findings suggest that highest number of nine factors determine the adaptive capacity of people against the livelihood insecurity that results from severe constraints in fishing-related activities. Among these nine factors, three are related to demographic and socioeconomic aspects; four factors are related to adaptation behaviors. One factor from each of climate/weather information/ knowledge products and physical environmental category significantly influence the adaptive capacity against the livelihood insecurity results from severe constraints in fishing-related activities. As a whole, adaptive behavioral factors have the highest influence followed by demographic and socioeconomic factors. Livelihood insecurity that results from severe damage in physical and socioeconomic infrastructures is significantly determined by eight factors. Among these eight factors, four factors are related to the demographic and socioeconomic aspects of people. Two factors are related to people's adaptation behaviors. Another two factors are linked to the physical environment where the livelihood of people operates. Highest number of two physical environmental factors determine people's adaptive capacity against the impacts that result from severe damage in physical and socioeconomic infrastructures. Climate/weather information and knowledge products-related factors do not have statistically significant

Table 11 Summary of factors influencing various dimensions of livelihood insecurity

Whether the listed factors influence livelihood insecurity	LISD-1	LISD-2	LISD-3	LISD-4
Demographic and socioeconomic:				
Respondent's age				
Respondent's sex	√			
Respondent's education		√		
Respondent's occupation		√	√	
Family's landholding	√	√	√	
Membership of social group	√	√	√	√
Social capitals				√
Adaptive behavioral factors:				
Adaptation against rainfall			√	√
Adaptation against flood		√	√	
Adaptation against drought			√	
Adaptation against salinity	√	√	√	
Climate/weather information:				
Radio				
Television	√			
Newspaper	√			√
Peer network				
Official sources				√
Adherence to information			√	
Physical environmental factors:				
Distance from the shoreline		√		
Distance from the safe shelters			√	√
Accessibility to safe shelter		√		
Change of settlement				

Note: LISD-1: Livelihood insecurity results from severe constraints in agriculture; LISD-2: Livelihood insecurity results from severe damage in physical and socioeconomic infrastructures; LISD-3: Livelihood insecurity results from severe constraints in fishing related activities; LISD-4: Livelihood insecurity results from severe crisis of freshwater and public health risk.

influence on this group of adaptive capacity. Adaptive capacity against the impacts of livelihood insecurity that results from severe constraints in agriculture and allied activities is primarily determined by three demographic and socioeconomic factors. Physical environmental factors do not have any statistically significant influence on this adaptive capacity. Finally, the adaptive capacity against the livelihood insecurity that results from severe crisis of freshwater and public health risk is determined by six factors. Among these factors, two are related to demography and socioeconomic aspects and another two are related to use of climate/weather information products. Both adaptive behavioral and physical environmental factors have limited influence on this adaptive capacity. In sum, adaptive behavioral factors are the strongest determinants of people's adaptive capacity against the livelihood insecurity that results from severe constraints in fishing-related activities. Conversely, demographic and socioeconomic factors are the strongest determinants of adaptive capacity against the livelihood insecurity that results from severe damage in physical and socioeconomic infrastructures. Physical environmental factors have highest influence on adaptive capacity against the livelihood insecurity that results from severe damage in physical and socioeconomic infrastructures as well (Table 11).

Concluding Remarks

Increasing numbers of literature stress the importance of identification of factors that determine the adaptive capacity of people against the impacts of natural disasters. In the changing context of climate as both the frequency and the magnitude of some of the hydrometeorological events are projected to increase this call for a fresh look at the impacts of these events on livelihood security of the coastal people. This chapter first established the ground of amplification of various hydrometeorological disastrous events in coastal Bangladesh. It then identifies the likely threat of various hydrometeorological events on the livelihood security of natural resource-dependent coastal community in Bangladesh taking Kalapara Upazila (subdistrict) as the case study. Employing the PCA analysis from a long list of sources/causes of livelihood insecurity, four major dimensions of insecurity are identified. Therefore, the livelihood insecurity against which adaptive capacity need to be enhanced are (a) severe constraints in agriculture farming and allied activities; (b) severe damage of physical and socioeconomic infrastructures; (c) severe constraints in fishing (mostly offshore) related activities; and (d) severe crisis in freshwater supply and public health risk. At this point, the question arises how to intervene to enhance these four dimensions of adaptive capacity of peoples. It is highly unlikely that adaptive capacity of every one need to be enhanced in the same way. Hence, it is important to determine the characteristics that are associated with different dimensions of adaptive capacity. The multiple ANOVA techniques were employed to determine the influences of four groups of variables, namely, demographic and socioeconomic, past adaptive behavioral, climate/weather information/knowledge products, and physical environmental (spatial/locational) aspects on four dimensions of adaptive capacity.

The findings are robust. Among the demographic and socioeconomic factors, sex, education, occupation, farmland holding, membership status (of social institution), and assistance from neighbor/relative have the strongest influence on differential adaptive capacity in general. The influence of other demographic and socioeconomic factors is not statistically significant. Similarly, among the past adaptive behavioral factors, except the freshwater crisis, all other variables, namely, flood, rainfall, and salinity intrusion have strong influence in making difference in adaptive capacity. Likewise, among the climate/weather information/knowledge products, almost all have limited influence on various dimensions of adaptive capacity. However, contrary to expectation no statistically significant influence of radio on adaptive capacity is identified. This finding does not follow most literatures on the burgeoning role of information communication media on adaptive capacity. Therefore, this finding has to be triangulated with more in-depth study before making any conclusion about the role of information channels on adaptive capacity. This seems to be a weakness of this research as well. On the positive side, it can be argued that this research opens up a new avenue of further exploratory research. Similarly, all the physical environmental (spatial/locational) factors have limited influence on differential adaptive capacity of coastal people. Finally, it could be argued that while all the four major group of factors are important determinants of adaptive capacity against hydrometeorological disastrous events in coastal Bangladesh, the past adaptive behavior against flood, rainfall, salinity intrusion, and the few others socioeconomic factors, such as occupational engagement, land holding, and educational attainment are the key drivers of peoples adaptive capacity. Considering the heavy influence of most of the adaptive behavioral factors it can be said that the past experience of adaptation probably the cause of the winning the battle of the resource poor coastal people of Bangladesh against the various hydrometeorological disasters throughout the history. This finding stresses the importance of nurturing of local/traditional/indigenous knowledge of adaptation alongside initiation of programs for livelihood vulnerability reduction. Finally, it is concluded that rather than launching very generic program for adaptive capacity building of the coastal inhabitants in general, specific program may be initiated for specific group of natural resource-dependent coastal people whose livelihood are vulnerable to specific impacts of various hydrometeorological disastrous events. This finding can help policy makers and planners alike in identifying people in need of specific adaptive capacity enhancement program.

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Mainstreaming Integrated Climate Change Adaptation and Disaster Risk Reduction in Local Development Plans in the Philippines

Ebinezer R. Florano

Contents

Abstract

This chapter illustrates how the two conceptually distinct climate change adaptation (CCA) and disaster risk reduction (DRR) are mainstreamed in the development plans of local government units in the Philippines using integrated frameworks for vulnerability analysis and the development of climate-resilient local Comprehensive Land Use Plan (CLUP) and Comprehensive Development Plan (CDP) prescribed by the national government. The integration of CCA and DRR in the Philippines came after the failure of the passive disaster management, utilized since 1954, to prepare and response to disasters caused by extreme weather events of climate change. Using the case study approach, this chapter narrates how disaster-prone Sorsogon City was able to incorporate CCA and DRR measures and strategies in its CLUP and CDP.

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Mainstreaming • Climate change adaptation • Disaster risk reduction • Vulnerability analysis • Local development planning

Introduction

Climate change adaptation (CCA) and disaster risk reduction (DRR) have always been treated as two distinct epistemic communities in scholarly literature (Mercer 2010; Schipper and Pelling 2006; Tearfund 2008; Thomalla et al. 2006; UNISDR 2008a, b, c). Thus, it is no wonder that even in practice, the two coexist, but they are operationalized independently of one another. In the Philippines, for example, there are two separate laws on climate change (CC) and disaster risk reduction and management (DRRM), namely, the *Climate Change Act of 2009* (Republic Act No. 9729 or RA 9729) and the *Philippine National Disaster Risk Reduction and Management Act of 2010* (Republic Act No. 10121 or RA 10121), respectively. They are implemented by separately funded national government agencies – the Climate Change Commission (CCC) and the National Disaster Risk Reduction and Management Council (NDRRMC). Both laws mandate local government units (LGUs), namely, provinces, cities, municipalities, and *barangays* (villages), to mainstream their local CCA and DRR plans to their local development plans. Is this possible, given the conceptual and operational divide between CCA and DRR? Can the two be reconciled? Can an integrated CCA and DRR be mainstreamed in local development plans? To answer these questions, this study revisits the discourses on the similarities, differences, and signs of convergence between the two communities. It also examines the nexus between the two based on the implementation of the CC and DRRM laws in the Philippines. Finally, using a case study on an LGU, this chapter proves that, indeed, the two can be integrated and mainstreamed in local development plans.

Similarities, Differences, and Points of Convergence Between CCA and DRR

Theoretically speaking, it is inconceivable to integrate CCA and DRR primarily because of their temporal and spatial nuances. According to generally accepted views, CC-induced hazards and disasters are less predictable because they are based on projections of the atmospheric and ocean conditions which are still to happen in the future, while non-CC-related hazards and disasters are studied based on historical records and, hence, are relatively predictable. Second, due to the uncertainties in projecting CC, its impacts are difficult to calculate, while those in DRRM are easily discernible because it relies on records to determine the extent of damages that can be caused by particular hazards in the future. Third, in terms of origin, CC originated from scientific theory, while DRRM evolved out of the need to

Table 1 Summary of similarities, differences, and signs of convergence between CCA and DRR

DRR	CCA	Signs of convergence
Relevant to all hazard types	Relevant to climate-related hazards	Not applicable
Origin and culture in humanitarian assistance following a disaster event	Origin and culture in scientific theory	CCA specialists now being recruited from engineering, agriculture, health and DRR sectors
Most concerned with the present – i.e., addressing existing risks	Most concerned with the future – i.e., addressing uncertainty/new risks	DRR increasingly forward-looking
		Existing climate variability is an entry point for CCA
Historical perspective	Future perspective as above	Same as above
Traditional/indigenous knowledge at community level is a basis for resilience	Traditional/indigenous knowledge at community level may be insufficient for resilience against types and scales of risk yet to be experienced	Examples where integration of scientific knowledge and traditional knowledge for DRR provides learning opportunities
Structural measures designed for safety levels modelled on current and historical evidence	Structural measures designed for safety levels modelled on current and historical evidence and predicted changes	DRR increasingly forward-looking
Traditional focus on vulnerability reduction	Traditional focus on physical exposure	Not applicable
Community-based process stemming from experience	Community-based process stemming from policy agenda	Not applicable
Practical application at local level	Theoretical application at local level	CCA gaining experience through practical local application
Full range of established and developing tools	Limited range of tools under development	None, except increasing recognition that more adaptation tools are needed
Incremental development	New and emerging agenda	Not applicable
Political and widespread recognition often quite weak	Political and widespread recognition increasingly strong	None, except that climate-related disaster events are now more likely to be analyzed and debated with reference to CC
Funding streams ad hoc and insufficient	Funding streams sizeable and increasing	DRR community engaging in CCA funding mechanisms

Source: Tearfund 2008, p. 10

provide humanitarian assistance to disaster victims (Mercer 2010; ProAct Network 2008; Schipper and Pelling 2006; Tearfund 2008; Thomalla et al. 2006; UNISDR 2008a, b, c). There are many other points of divergence between the two (as can be seen in Table 1), but there are also points of convergence, the most important of which is to reduce risk and enhance resilience.

Table 2 General characterizations of the CCA and DRR communities in the Philippines

DRR	CCA
Organizations and institutions	
United Nations	UN Framework Convention on Climate Change
ProVention Consortium (the World Bank)	Intergovernmental Panel on Climate Change
International Federation of Red Cross and Red Crescent Societies	Academe and research
International, national, and local civil society groups and NGOs	National and local NGOs
National DRRM Council	Climate Change Commission
Department of National Defense as lead agency	Departments of Environment and Natural Resources, Agriculture, Energy, and National Economic and Development Authority
Departments of the Interior and Local Government, Social Welfare and Development, Science and Technology, and National Economic and Development Authority	
Strategies	
National Disaster Coordinating Council Response Systems	National Communication to the UNFCCC
UN International Strategy for Disaster Reduction	National Framework Strategy on Climate Change
Hyogo Framework of Action	National Climate Change Action Plan
Four-point Agenda from 2005 National Disaster Risk Reduction and Management (NDRRM) Framework	
Strategic National Action Plan for Disaster Risk Reduction (SNAP)	
Major policies	
Philippine Disaster Risk Reduction and Management Act of 2010 (Republic Act No. 10121), 27 May 2010	Philippine Climate Change Act of 2009 (Republic Act No. 9729), 23 October 2009
Adopting SNAP and institutionalizing DRR (Executive Order No. 888), 7 June 2010	
Funding	
National DRRM Fund	Special Climate Change Fund
International Humanitarian Funding	People's Survival Fund (Republic Act No. 10174), 25 July 2011
Multilateral Bank	
Bilateral Aid	

Source: Modified and updated from Lasco and Delfino 2010, pp. 54–55

In the Philippines, it is argued that there are "conceptual" and "operational" divide between CCA and DRR in terms of approach, organization and institutions, strategies, policies, and funding as shown in Table 2.

Initially, "conceptual divide" permeated the debates between CCA and DRR in the Philippines immediately after the laws that created them were passed.

However, not long afterward, it was finally recognized that although the two are distinct fields, they are connected in their objective to reduce risk to CC-induced hazards and disasters. While DRR deals with both man-made and "natural disasters" caused by geophysical and ecological hazards, it is also concerned with climate- and weather-related hazards which fall within the ambits of CC, i.e., gradual changes in climatic parameters (e.g., sea-level rise, rising mean temperature, and changes in precipitation patterns) and extreme weather events with increased frequency and severity. Figure 1 below illustrates the conceptual convergence between the two.

The "operational divide" is believed to be the most persistent issue between the two because the evidences are clear – two distinct laws, two government agencies, separate budgets, and distinct approaches. Although CCA came a year ahead (through the *Climate Change Act of 2009*) of DRR (through the *Philippine National Disaster Risk and Management Act of 2010*) in terms of enactment, the latter has been institutionalized since 1954 with the creation of the National Civil Defense Administration via Republic Act No. 1190 also known as the *Civil Defense Act of 1954*. Seven presidential issuances after that law, the National Disaster Coordinating Council was created through Presidential Decree No. 1566 issued in 1978. Hence, DRR acquired "seniority" over CCA and its operating agency (the NDRRMC) gets more funds, has a larger bureaucracy, has longer track record, and is relatively more technically competent to do its tasks. CCA and its operating agency (the CCC), on the other hand, is still in its infancy stage. Yet, a closer scrutiny of the laws, institutional and operational arrangements reveal points of operational convergence.

First, both laws, even though they use two interventions, i.e., adaptation and disaster mitigation, aim to reduce risks or vulnerabilities from natural hazards.

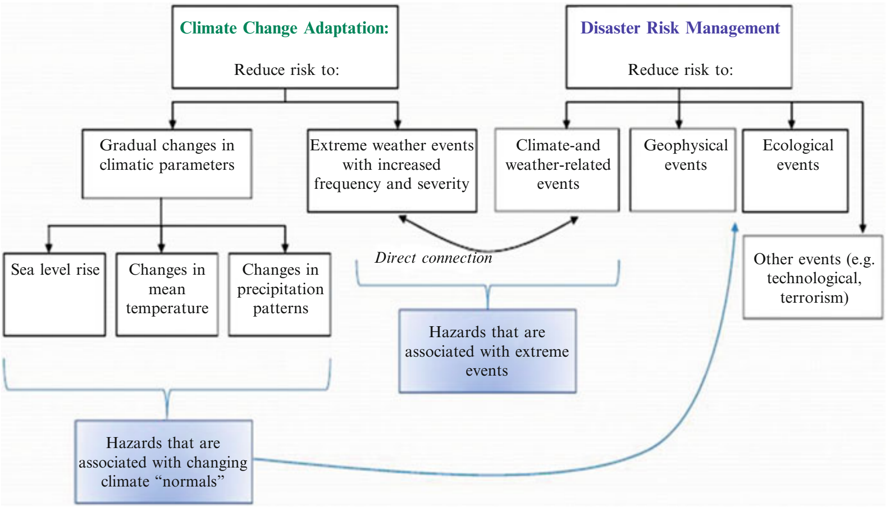

Fig. 1 CCA and DRR: point of conceptual convergence (Source: Gotangco 2012)

- **Section 3n of the *CC Act of 2009*:** Adaptation – "refers to the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, *which moderates harm or exploits beneficial opportunities*"
- **Section 3 of the *DRRM Act of 2010*:** Disaster mitigation – ". . .Structural and non-structural measures undertaken to limit the adverse impact of natural hazards, environmental degradation and technological hazards and to ensure the ability of at-risk communities *to address vulnerabilities aimed at minimizing the impact of disasters. . .*"

Thus, the visions of the two, as contained in their national plans of action, for a climate-resilient Philippines also converge:

- ***National Climate Change Action Plan (NCCAP)***: "Build the adaptive capacities of women and men in their communities, *increase the resilience of vulnerable sectors and natural ecosystems to climate change* and optimize mitigation opportunities towards gender-responsive and rights-based sustainable development."
- ***National Disaster Risk Reduction and Management Plan (NDRRMP)*:** "Safer, *adaptive and disaster-resilient Filipino communities* toward sustainable development."

Second, both laws recognize the two fields (CCA and DRR) and their interrelationships:

- **Section 2 of the *CC Act of 2009*:** "Further recognizing that climate change and disaster risk reduction are closely interrelated and effective disaster risk reduction will enhance climate change adaptive capacity, *the State shall integrate disaster risk reduction into climate change programs and initiatives*."
- **Section 6 (n) of the *DRRM Act of 2010*:** "*In coordination with the Climate Change Commission, formulate and implement a framework for climate change adaptation* and disaster risk reduction and management from which all policies, programs and projects shall be based. . ."

Third, both laws aim to mainstream CCA and DRR in local development plans. The *CC Act of 2009* mandates all government agencies to draw up their CC action plans which are going to be mainstreamed, in synergy with DRR, in national, sectoral, and local development plans. On the other hand, the *DRRM Act of 2010* orders all local governments to come up with their local DRRM plans which are going to be incorporated in their CLUPs and CDPs.

Fourth, the CCC and NDRRMC are headed by the President of the Philippines as their chairman. Hence, should conflicts arise, they can be resolved under the supervision of one person – the President of the Philippines.

Fifth, heads of both agencies are members in the decision-/policy-making units of the other. The Executive Director of the Climate Change Office (CCC) is a council member of the NDRRMC. On the other hand, the chair of the NDRRMC (i.e., Secretary of National Defense) is a member of the advisory board of the CCC.

Sixth, even though the CCC and the NDRRMC have separate budgets at the national level, local governments are free to use their 5 % Local DRRM Fund and 20 % Local Development Fund for CCA- and DRR-related activities.

Seventh, in a memorandum of understanding for collaboration program on Philippine climate risk reduction signed in April 2011, the NDRRMC and the CCC pledged to work together to harmonize, coordinate, and support the implementation of the local CC action plans and local disaster risk reduction and management plans of LGUs (NDRRMC-CCC 2011).

Last, the most important of all, the operational plans of the CCC's *NCCAP* and the NDRRMC's *NDRRMP* have integrated the activities of both fields. In the *NDRRMP*, all DRR phases (i.e., mitigation and prevention, preparation, rescue and relief, and recovery and rehabilitation) integrate two major priority areas of the CCC's *NCCAP*, namely, "human security agenda" and "ecosystem and environmental stability" (see Table 3). Majority of these integrated CCA and DRR operational activities can be mainstreamed in the local development plans of LGUs.

Mainstreaming CCA and DRR in Local Development Plans

LGUs in the Philippines are mandated to formulate two major local plans which serve as the entry points for CCA and DRR integration. These are the Comprehensive Land Use Plan (CLUP) and the Comprehensive Development Plan (CDP). They are both formulated with guidance from political leaders' visions for their localities and constituencies. Ideally, the CLUP is formulated first to serve as framework for the CDP and other plans (see Fig. 2). However, the planning of both the CLUP and the CDP can proceed simultaneously once the visions of the local leaders are known and have been validated.

Integrating CCA and DRR in the CLUP

The CLUP is the long-term (10–15 years) physical development plan for the management of local territories. It is formulated by the local planning and development office and approved by the local legislative council, i.e., *Sangguniang Panlalawigan* (Provincial Legislative Council) in case of a province, *Sangguniang Panglungsod* (City Legislative Council) in case of a city and *Sangguniang Pangbayan* (Municipal Legislative Council) in case of a municipality.

CLUPs spell out local governments' land use policies in the areas of settlements, infrastructures, production areas, and protected areas. These land policies are aimed to rationally distribute population in the territory, ensure that the population has access to basic social and economic services and opportunities, protect the environment, and promote sustainable development.

CLUPs at the municipal and city levels must be aligned with their higher counterparts, i.e., Provincial Physical Framework Plan, Regional Physical Framework Plan

Table 3 Points of integration of the operational plans of the *NCCAP* and the *NDRRMP*

NCCAP	NDRRMP
Human security agenda	
Conduct of provincial-level vulnerability and risk assessments	Prevention & mitigation
Mainstream and implement local plans based on information from the vulnerability and risk assessment	Prevention & mitigation
Develop and implement knowledge management on CC and disaster risks	
Increase local and community capacities for CCA/DRRM	
Integrate CC and DRR in the training of health personnel and community workers	Crosscutting concerns Strategies Prevention & mitigation Preparedness
Improve system for health emergency preparedness and response for climate and disaster risks	
Improve system for post-disaster health management	
Develop a long term plan for adaptation of highly CC vulnerable population and climate refugees	Prevention & mitigation
Extensive IEC program on CC risks and population management	Strategies Prevention & mitigation Preparedness
Ecosystem and environmental stability	
Conduct a nationwide gendered ecosystem vulnerability and risk assessment	Crosscutting concerns Prevention and mitigation
Derive and implement mitigation and adaptation strategies for key ecosystems	
Implement the National REDD Plus Strategy	Prevention and mitigation
Expand the network of protected areas (PAs) and key biodiversity areas (KBAs)	Prevention and mitigation
Establish ecosystem towns or eco-towns in PAs and KBAs	Prevention and mitigation
Design gender-fair innovative financing mechanisms and a bundle of CC adaptation assistance for eco-towns/communities	Crosscutting concerns
Implement moratorium on polluting and extractive industries in PAs, KBAs, and other environmentally critical areas	Prevention and mitigation
Increase knowledge and capacity for integrated ecosystem-based management at the national, local, and community levels	Strategies Prevention and mitigation Preparedness
Review and revise Philippine Economic-Environmental and Natural Resources Accounting (ENRA)	Prevention and mitigation
Implement training programs on wealth accounting or ENRA for key government agencies	Prevention and mitigation

Source: NDRRMC 2011, p. 65

and National Physical Framework Plan (see Fig. 3). Once approved, the CLUPs are enforced through zoning ordinances (ZOs) and become the basis for the formulation of CDPs (refer again to Fig. 2).

In the preparation of CLUPs, the Housing and Land Use Regulatory Board (HLURB), a national quasi-judicial government agency tasked in planning and regulating housing and land development matters, prescribes the following 12-step

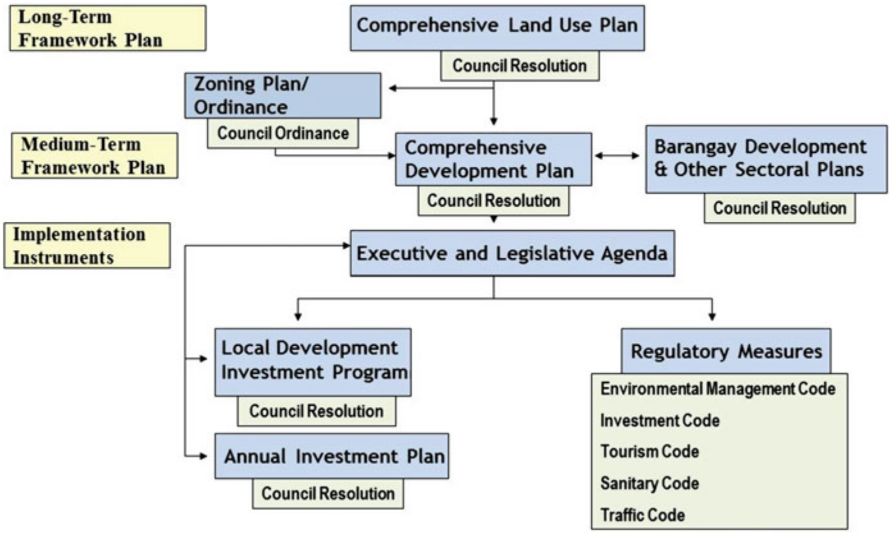

Fig. 2 Level of local development plans (Source: DILG-BLGD 2008, p. 19)

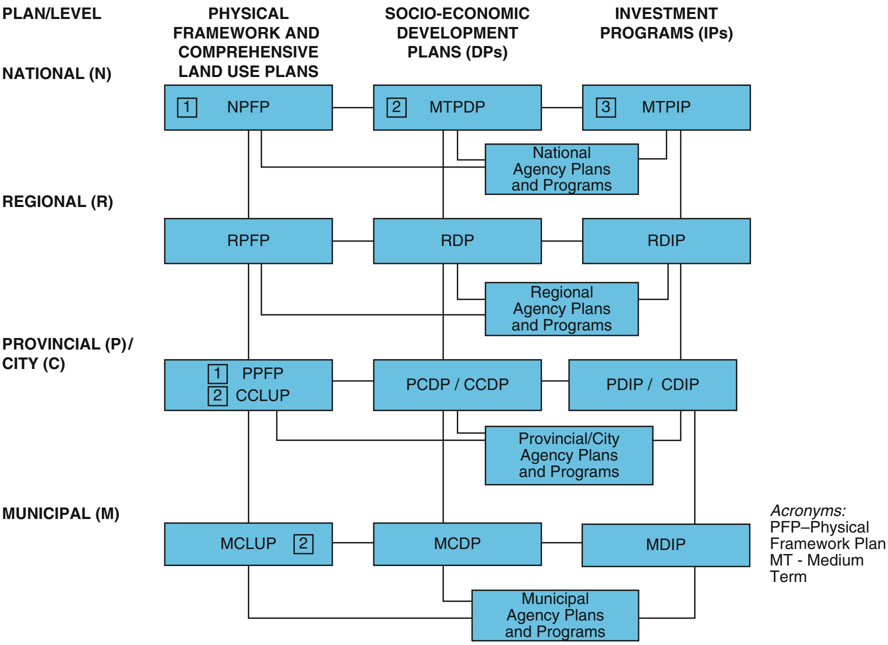

Fig. 3 Hierarchy and linkages of plans (Source: HLURB 2006, p. 4)

process for comprehensive land use planning: (1) getting organized; (2) identifying stakeholders; (3) setting the vision; (4) analyzing the situation; (5) setting the goals and objectives; (6) establishing the development thrust and spatial strategies; (7) preparing the land use plan; (8) drafting the ZO; (9) conducting public hearing on the draft CLUP and ZO; (10) reviewing, adopting, and approving the CLUP and ZO; (11) implementing the CLUP and ZO; and (12) monitoring, reviewing, and evaluating the CLUP and ZO. In 2011, the HLURB, in consultation with CC and DRRM experts, identified the entry points of CCA and DRR in each step of the planning process. The factors considered were funds, CC/DRRM experts/agencies' involvement; inclusion of CC and DRR concepts, measures, strategies, and indicators in each step; etc. For details, see Table 4.

Integrating CCA and DRR in the CDP

The CDP contains the multi-sectoral medium-term (6 years) plans of a local government that promote the general welfare of its inhabitants. It consolidates the goals, objectives, strategies, programs, projects, and legislative measures of the following development sectors: economic, social, environmental, physical/infrastructure, and institutional.

CDPs are crafted by Local Development Councils (LDCs) which are composed of technical experts and political leaders. At the technical side, members include representatives from local special bodies (e.g., local school board), sectoral and functional committees, department heads, local planning and development office, national government agencies and private sector. At the political side, there are representatives from the LDC itself, local legislative council, the congressional representative and civil society organizations. LDCs are chaired by local chief executives.

A CDP's timeframe is coterminous with the term of the elected local chief executive. Once a CDP has been written, it serves as inputs to Executive-Legislative Agenda (ELA) of the local leaders. The development sectors' programs and projects are then incorporated in the Local Development Investment Program (LDIP) which, in turn, is implemented through the Annual Investment Program (AIP) and the Annual Budget (AB). Refer to Fig. 2 above and Table 5 below for the hierarchy and relationship of these major local government plans.

In 2008, the National Economic and Development Authority (NEDA), the central planning agency of the Philippines, published the *Guidelines on Mainstreaming Disaster Risk Reduction in Subnational Development and Land Use/Physical Planning*. It is a tool to improve regional and provincial planning analysis by recognizing risks posed by natural hazards and the vulnerability of the population, economy, and the environment to these hazards.

The guidelines were initially focused on mainstreaming DRR to CLUPs, CDPs, and other local development plans because, as was stated before, the Philippines has a long history with disaster management. Later, CCA was incorporated into the DRR mainstreaming framework.

Table 4 Entry points for CCA/DRR integration into the 12-step planning process for CLUP

Step no.	Process	Entry point for CCA/DRR integration
1	**Getting organized** Getting endorsement/approval from local legislative council Preparation of work program Organization and briefing of planning team	Include budget for DRR/CCA Involve representative from DRR Office in the planning team
2	**Identify stakeholders** Listing of stakeholders Action planning Information dissemination	Involve DRR/CCA stakeholders and collective strengthening on community awareness on natural disasters (CSCAND) agencies
3	**Setting the vision** Conduct of visioning workshops Adoption of vision and informing the public	Include DRR/CCA concepts in the vision (e.g., "safety," "secured," "climate resilient," "climate proof," etc.)
4	**Situation analysis** Data gathering and land use surveys Base map preparation Sectoral studies and physical/land use studies Mapping of results Consultation/validation workshops Need/issues analysis and projections Cross-sectoral analysis and integration	Conduct CCA/disaster risk assessment and vulnerability assessment Conduct adaptive capacity assessment Use results to conduct analysis of climate change/risk impacts to land use and exposed population, socioeconomic conditions, infrastructure system Identify/propose policies/mitigating/adaptation measures
5	**Setting the goals and objectives** Goals and objectives formulation workshops	Identify development issues and their translation to goals, objectives, and targets Include CCA/DRR concepts in the goals, objectives, and targets
6	**Establishing desired development thrust and defining spatial strategies** Development options Preferred development thrust and spatial strategy Structure plan/conceptual framework plan	Consider CCA/DRR strategies and measures to respond to identified CC/DR
7	**Preparing the land use plan** Proposed land and water uses policies Proposed circulation network Major development programs/projects	Involve representative from DRR office in the planning team Ensure land use and zoning policies address identified CC/DR such as disaster risk zoning Identify CCA/DRR projects, plans, and activities (PPAs)
8	**Drafting of zoning ordinance (ZO) and other development controls**	Involve representative from DRR office in the planning team Ensure land use and zoning policies address identified CC/DR such as disaster risk zoning Identify CCA/DRR projects, plans, and activities (PPAs)

(*continued*)

Table 4 (continued)

Step no.	Process	Entry point for CCA/DRR integration
9	**Conduct public hearing** Conduct of public hearings/ consultations Refinement of draft CLUP and ZO	
10	**CLUP review/adoption and approval** Endorsement for review of appropriate body Conduct of review by appropriate body Refinement of CLUP by local government unit Local legislative council adoption of refined CLUP Endorsement to local legislative council/ HLURB for ratification/approval Ratification of local legislative council/ HLURB	Involve representative from DRR office in the regional/provincial land use committee (RLUC/PLUC)
11	**Implementing the CLUP** Required operating bodies/offices Permitting and clearance system CDP-LDIP-AIP-PPP implementation	Ensure strict implementation of CCA/ DRR-enhanced CLUP and ZO
12	**Monitoring, reviewing, and evaluating the CLUP**	Include CCA/DRRM indicators in the monitoring and evaluation system Continually monitor level of disaster risks/CC effects and emerging threats

Source: HLURB 2012

Acronyms: *CDP* Comprehensive Development Plan, *LDIP* Local Development Investment Plan, *AIP* Annual Investment Plan, *PPP* public-private partnership

At first, the guidelines advise LGUs to undertake disaster risk assessment (DRA). Briefly, DRA involves the following: (a) hazard characterization/frequency analysis, (b) consequence analysis, (c) risk estimation, and (d) risk prioritization. Below are the summaries for each of the processes involved in each step of DRA:

Hazard characterization/frequency analysis – the in-depth study and monitoring of hazards to determine their potential, origin (i.e., geologic or hydrometeorologic), geographical extent, and hazard impact characteristics including their magnitude-frequency behavior, historical behavior, and initiating (or triggering) factors

Consequence analysis – determining or defining the elements at risk from a given hazard and defining their vulnerability

Risk estimation –involves the integration of the results of *hazard characterization and frequency analysis* (or *hazard analysis)* with *consequence analysis* to derive an overall measure of risk

Risk prioritization – is undertaken to guide the identification of areas needing urgent attention

Source: NEDA-UNDP-ECHA 2008, pp 35–47

Table 5 Major plans of local government units

Plan	Definition	Main contents	Timeframe
Comprehensive Land Use Plan (CLUP)	Policy guide for the regulation of land uses embracing the LGU's entire territorial jurisdiction	Policies on settlements, protected areas, production areas, and infrastructure	10–15 years
Comprehensive Development Plan (CDP)	Multi-sectoral (economic, social, environmental, physical/infrastructure, institutional) plan to promote the general welfare of the LGU	Sectoral goals, objectives, strategies, programs, projects, and legislative measures	6 years
Executive-Legislative Agenda (ELA)	Term-based counterpart of the CDP	Sectoral goals, objectives, strategies, prioritized programs and projects, and legislative measures	3 years
Local Development Investment Plan (LDIP)	Principal instrument for implementing the CDP and ELA	Prioritized projects, plans and activities (PPAs) and program for planned financing	3 years
Annual Investment Plan (AIP)	One year slice of the LDIP	Prioritized PPAs proposed for inclusion in the annual local budget	1 year

Source: DILG-NEDA-DBM-DOF 2007, p. 9

The results in the DRA are then mainstreamed in development planning through the following primary entry points: (a) analysis of the planning environment; (b) identification of issues and problems; (c) formulation of goals, objectives, and targets; (d) formulation of development strategies, and (e) identification of programs, projects, and activities (PPAs). Refer to Fig. 4.

Issues and problems are based on either existing or potential land use conflicts associated with the risks or their impacts to the developmental objectives of LGUs. From these analyses, goals, objectives, and targets are identified and refined according to the vision of local governments. Once these had been made, the corresponding interventions, in the forms of PPAs, of the local government vis–àvis the disaster risks are formulated and prioritized. These interventions may come in the form of the following measures: (a) risk avoidance or elimination, (b) risk reduction or mitigation, (c) risk sharing or transfer, and (d) risk acceptance or retention.

The secondary entry point for the mainstreaming of the integrated CCA/DRR is in the plan implementation stage. This involves investment programming, budgeting/financing, implementation, and monitoring and evaluation.

In investment programming, the LDIP is drafted. It is a prioritized list of PPAs for 3 years with the corresponding annual expenditures. The LDIP is then sliced into 1-year AIP whose expenditures are to be included in the annual local budget. Funds for the budget come from local development fund, local DRRM fund, local

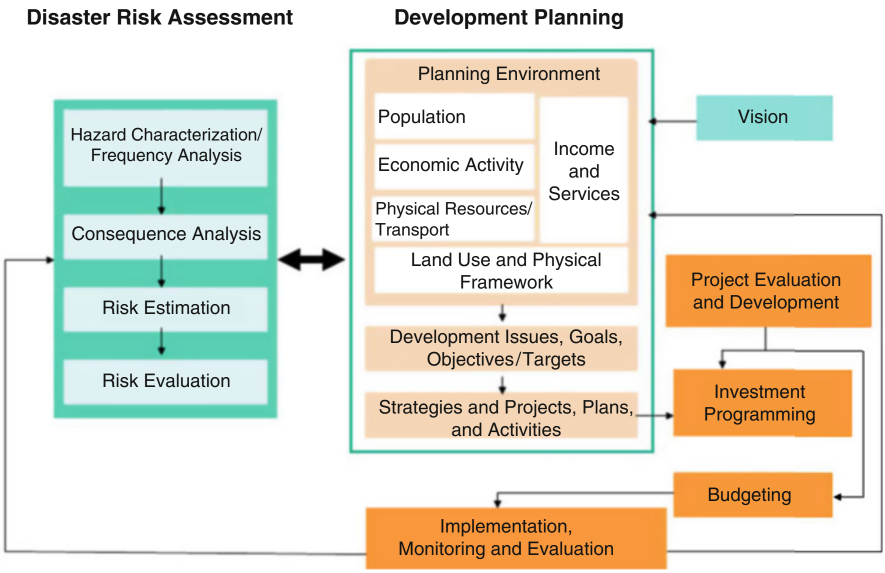

Fig. 4 Framework for mainstreaming DRR in subnational plans (Source: NEDA-UNDP-ECHA 2008, p. 32)

taxes, risk transfer/transfer financing, etc. The implementation of the PPAs are then monitored and evaluated to determine the project outcomes and impacts. Refer again to Table 5 for the details of these plans.

CC was later incorporated into the DRA mainstreaming framework. In the area of risk assessment, climate scenarios based on projected temperature and precipitation data are incorporated in hazard characterization/frequency analysis. Sectoral impacts and their vulnerability are, then, integrated in consequence analysis and risk evaluation, respectively. See Fig. 5.

In the development planning stage of the mainstreaming framework, climate variability, sectoral impacts, and vulnerability analysis are incorporated in the planning environment (refer to Fig. 6). In particular, the effects and impacts of climate variability to population, economic activities, income and services, physical resources, transportation, land use, and physical framework are taken into consideration. The results of vulnerability analysis are, then, factored in the formulation of development issues, goals, objectives/targets, strategies, and PPAs.

Finally, a framework for integrating CCA and DRR into local development planning was conceived (see Fig. 7). The formulation of CCA/DRR-enhanced plans starts with the projection of CC scenarios in the future. Its impacts on various sectors (i.e., coastal areas, health, agriculture, water, forestry, etc.) and on known "natural" hazards (i.e., typhoons, earthquakes, rain- and earthquake-induced landslides) are then assessed using the DRA tool. Integrated CCA/DRR strategies are then identified and prioritized. These can be now included in the CDPs. Demonstration projects are implemented to pilot test the PPAs.

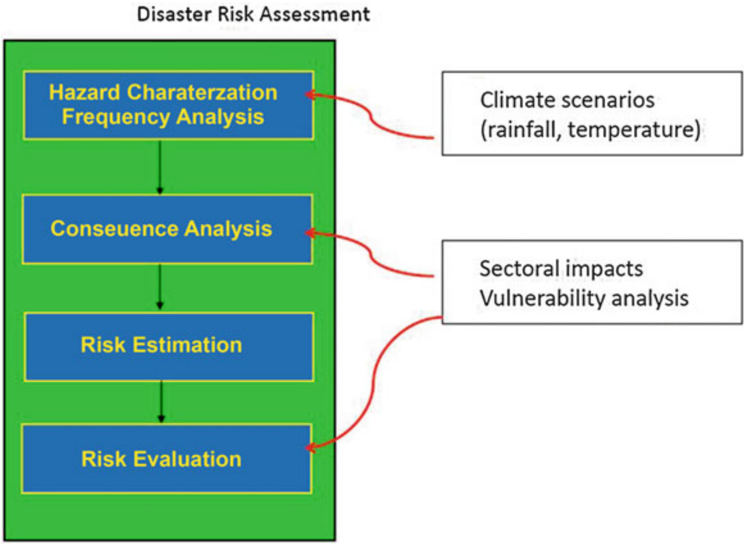

Fig. 5 Incorporation of climate change in disaster risk assessment (Source: De Guzman 2010)

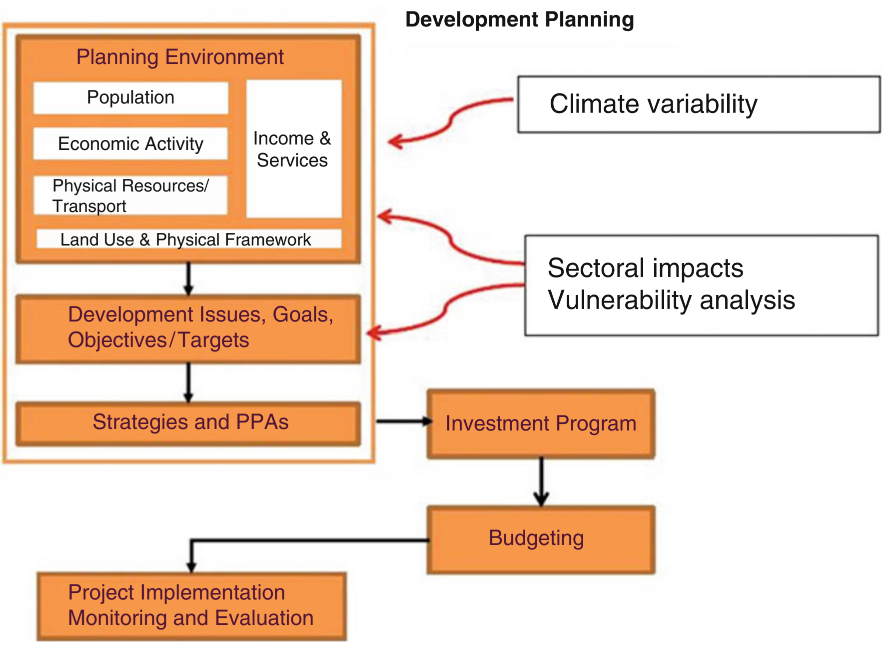

Fig. 6 Incorporation of climate change in local development planning (Source: De Guzman 2010)

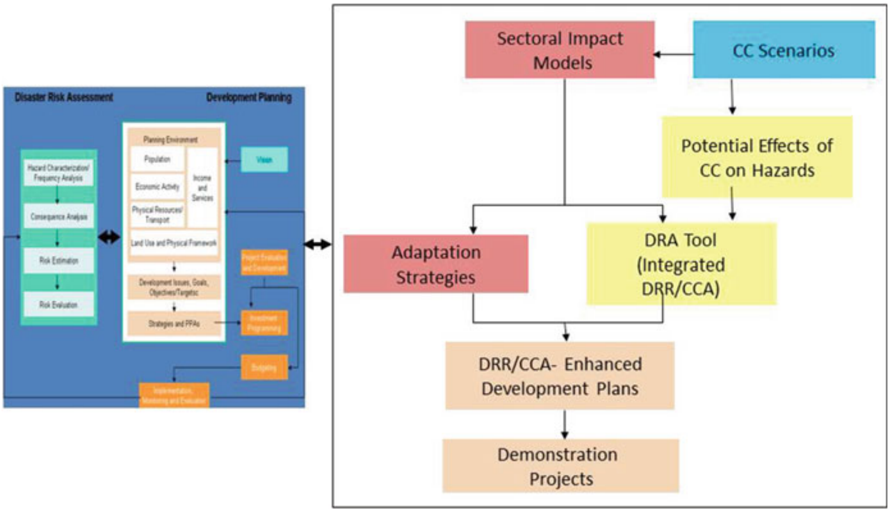

Fig. 7 Framework for the integration of CCA and DRR in local development planning (Source: De Guzman 2010)

The Integration of CCA and DRR in the Local Development Plans of Sorsogon City

Brief Profile of Sorsogon City

Sorsogon City, a component capital city of Sorsogon Province, was created in August 2000 through a national law (Republic Act 8806). The law combined two municipalities – Bacon and Sorsogon to create the new city. Sorsogon City is bordered in the east by Albay Gulf which opens up to the Pacific Ocean and in the west by Sorsogon Bay which is connected to China Sea, making it a coastal local government. Because of its geographical location, it is a transshipment corridor and gateway for the islands of Visayas and Mindanao (UN Habitat-Philippines n.d., p. 3) (see Fig. 8).

The city is the largest city in the Bicol Region – it measures up to 31,292 hectares (ha.) with 9,930 ha. dedicated to agriculture, 7,612.76 ha covered by forests, and 72 ha. for built-up areas. It is divided into three districts and 64 *barangays* (towns), 37 of which lie along the coastal areas. As of 2010, its population was pegged at 151,454 with an annual growth rate of 1.78 (in 2000–2007). It is the most populous city in the region (UN Habitat-Philippines n.d., p. 3).

The main economic activities in the city are agriculture, fishing, trade, and services. In the Philippine local government classification, the city is classified as second class for having obtained the second to the highest income among its peer

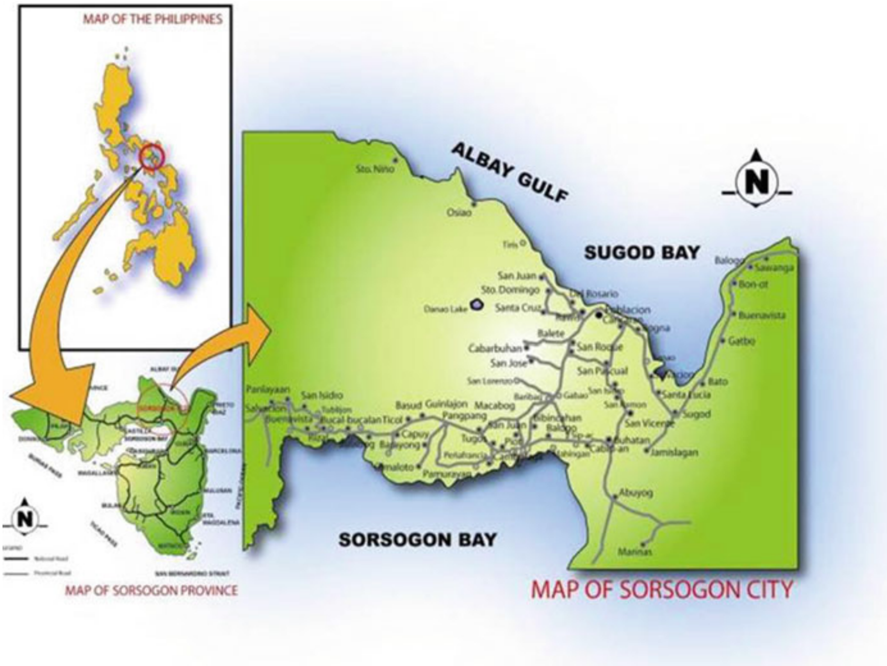

Fig. 8 Locational map of Sorsogon City (Source: UN Habitat-Philippines n.d., p. 3)

cities. As the capital city of Sorsogon Province, it serves as the latter's administrative, commercial, and educational center (UN Habitat-Philippines n.d., p. 3).

Sorsogon City's climate is classified as type II (Modified Coronas Classification System) where there is no dry season but with a pronounced rainfall from November to January. According to local data, rainfall usually starts late September or early October and rainfall ranges from 2,800 to 3,500 mm. Rains usually last 200 days in a year which continue even in the driest months (UN Habitat-Philippines n.d., p. 3).

The city experiences temperate temperature from 21 °C to 32 °C and relative humidity of 82 %. The prevailing winds are the monsoons and Pacific trade winds (which visits the city every April and May). From October to March, the northeast monsoon blows, while the southwest monsoon occurs from June to September. Unfortunately, the city is located at the Philippines' geographical zone 6 where three typhoons/cyclones pass every 2 years (UN Habitat-Philippines n.d., p. 7).

Vulnerability to Climate Change and Natural Disasters

According to the projections of the national government's meteorological agency (i.e., Philippine Atmospheric, Geophysical, and Astronomical Services Administration or

PAGASA), under the A1B scenario (using the PRECIS model of the UK Met Office Hadley Centre for Climate Prediction and Research), the whole province of Sorsogon, which includes the city, will experience 0.8–1.1 °C increase in temperature in 2020 and 1.5–2.1 °C in 2050 (UN Habitat-Philippines n.d., p. 10).

On the other hand, seasonal rainfall in the province and city will decrease by as much as –6.8 % in the March-April-May period and will increase from 5.1 % to 10.8 % in the other periods of the year 2020. By 2050, the decrease in seasonal rainfall in the March-April-May period will be almost double, –11.4 % and substantial increase to 7.4–27.3 % in the other periods of the year (UN Habitat-Philippines n.d., p. 10).

Owing to its geographical location and climatic conditions, it comes as a no surprise that it is always visited by strong tropical cyclones. In 2006 alone, two super tropical cyclones (locally named "Milenyo" in September and "Reming" in November) with more than 200 km per hour sustained maximum wind struck the city leaving more than 10,000 houses (33 % of the city's houses) and PhP208 million (around US$50 million at US$1 = PhP42) worth of damages. The city's poor and informal settlers were the hardest hit sector by the two typhoons which wiped out not only their houses but also their livelihoods. From the vulnerability assessment conducted by the city government, it is estimated that 34 coastal *barangays* out of 64 barangays (or 53 %) are in danger from strong surges brought by tropical cyclones (UN Habitat-Philippines n.d., pp. 10, 13).

Increase in rainfall is another direct CC problem by the city. With torrential rains, the city has experienced floods year in and year out. In 2009, for example, a weak storm (signal no. 1) brought extremely heavy rains to the city which measured 300 mm within a short period of time. It brought massive destruction worth PhP200 million (around US$48 million at US$1 = PhP42) in infrastructure and agricultural products. Again, from the vulnerability assessment of the city government, 20 *barangays* (or 31 % of 64 *barangays*) are prone to floods (UN Habitat-Philippines n.d., p. 15).

The city fears that it would also fall victim to sea-level rise (SLR) just like its neighboring city, Legaspi City, which had experienced seawater rising since 1970 from the Pacific Ocean. According to stories of local residents, SLR must have already taken place in Barangays Poblacion and Cambulaga where about 50 and 15 m of their lands were inundated by seawater since the 1950s. It is estimated by the city government that, again, 34 coastal *barangays* (53 % of 64 *barangays*) are in danger from SLR (UN Habitat-Philippines n.d., pp. 11, 18).

Landslide is another hazard that the city constantly faces. It comes with soil erosion and flashfloods which are triggered by increase in precipitation and volume of rainfall. Eight barangays or 13 % of 64 *barangays* have been identified as vulnerable to landslides (UN Habitat-Philippines n.d., p. 16).

In an assessment conducted by UN Habitat-Philippines in cooperation with the city government, it was found out that the city's adaptive capacity is low due to poor housing structures and infrastructure, climate-sensitive livelihoods, poor state of the environment, high health risks, etc. (for details, see UN Habitat-Philippines n.d., pp. 20–31).

Mainstreaming CCA and DRR into Sorsogon City's CLUP and CDP

The revisions in the CLUP and CDP of Sorsogon City were undertaken through the conduct of vulnerability and adaptation assessment (V&AA) and the integration of the V&AA findings into the CLUP and CDP

Vulnerability and Adaptation Assessment

In April 2009, UN Habitat-Philippines and the City Government of Sorsogon inked an agreement of cooperation which aimed to implement a project that will enhance the CC mitigation and preparedness of the city through the former's *Cities in Climate Change Initiative* (CCCI). The local project is under the *Strengthening Philippine Cities to the Impacts of Climate Change* program funded by the Millennium Development Goals Fund (MDGF)-1656, spearheaded by NEDA, and financially supported by the Spanish Government. Both sides provided financial, technical, and manpower assistance to implement the project.

The V&AA was conducted for the entire city to study the impacts of CC such as storm surges, strong typhoons, sea-level rise, increased precipitation, and higher temperature increase, especially to urban coastal settlements and hotspot areas

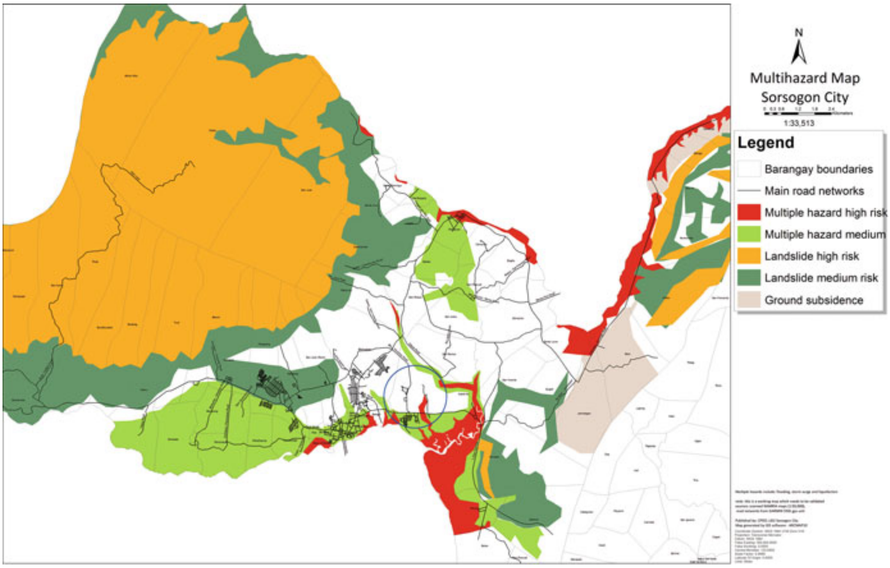

Fig. 9 A multi-hazard map of Sorsogon City (Source: Sorsogon City Government)

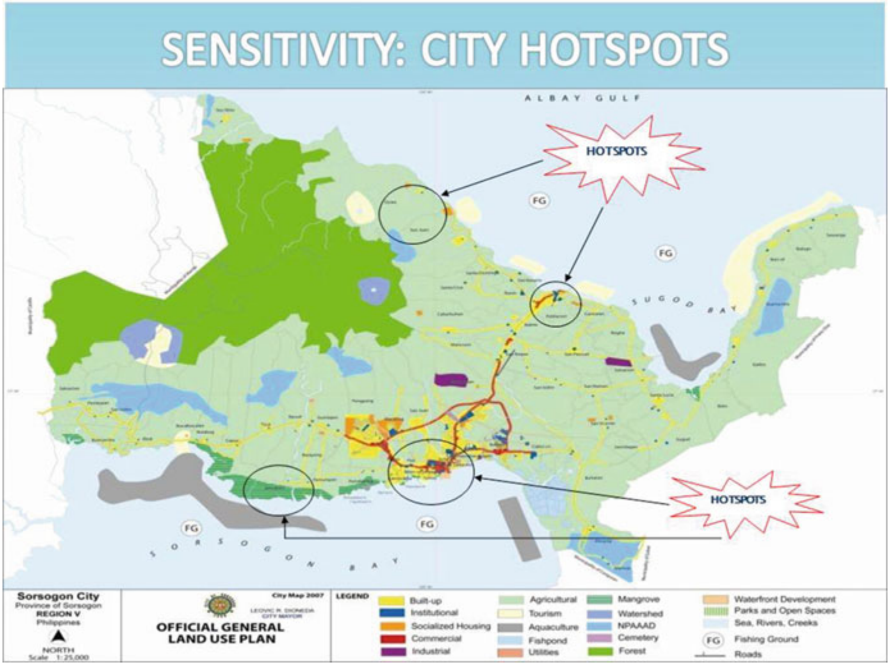

Fig. 10 Hotspot *barangays* (villages) in Sorsogon City (Source: Sorsogon City Government)

which are highly at risk. Briefly, the V&AA was conducted through the following processes:

(a) Collection of data/information on CC scenario (present and future), the socio-economic profile of the city, land use plan, maps, and the capacity of the city to address CC
(b) Analysis of the data to determine the vulnerability of the city by identifying the exposed elements (people, places, sectors, etc.), the sensitivity of the city, and its adaptive capacity
(c) Visualization of the CC hazards and risks through maps

In the visualization process, seven hazard maps were generated. These were for flood, ground subsidence, landslide, liquefaction, sea-level rise, storm surge, and tsunami. All of these were combined in multi-hazard maps, one of which is shown on Fig. 9.

It was found out from the multi-hazard maps that the following coastal *barangays* are vulnerable to the hazards and disasters that could be caused by CC: Cabid-an, Sampaloc, Sirangan, Bitan-o/Dalipay, and Talisay (see Fig. 10). Moreover, it was pointed out that the *barangay* residents have limited knowledge on CC, its impacts, and how to adapt. It was suggested that these *barangays* be made as sites of demonstration projects for CCA and DRR. These findings and

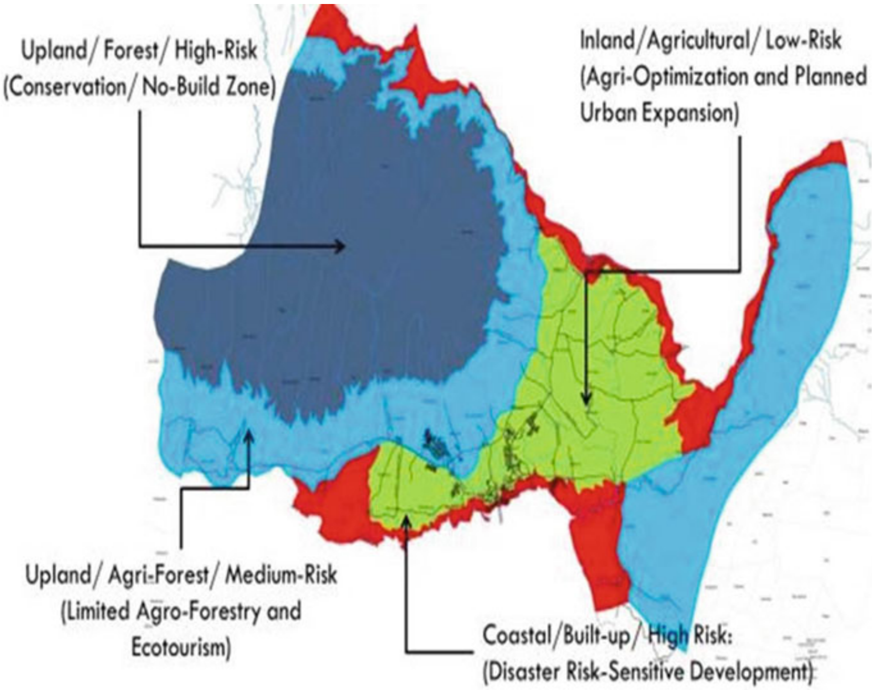

Fig. 11 Four policy zones in Sorsogon City (Source: Sorsogon City Government)

suggestion were validated in a multi-stakeholder consultation conducted in May 2009. In the same consultation, the following sectors were prioritized: housing and urban infrastructure, livelihood, environmental management, and disaster risk management. Workshops were also conducted for these four sectors to identify specific short- and long-term action plans.

Mainstreaming CCA/DRR in the CLUP and CDP

In July 2010, UN Habitat-Philippines and the Sorsogon City Government agreed to make the city the pilot site of mainstreaming the integrated CCA/DRR in its CLUP and CDP. This move received financial and technical support from the Swedish International Development Cooperation Agency (SIDA) and the Department of the Interior and Local Government (DILG).

The mainstreaming processes were composed of the following steps:

1. Assessment and updating of the existing situation
2. Assessment and updating the vision and development goals and objective
3. Assessment and updating of a 15-year CLUP and long-term (15 years) CDP and updating of medium-term (6 years) CDP and 3 years Executive-Legislative Agenda (ELA)

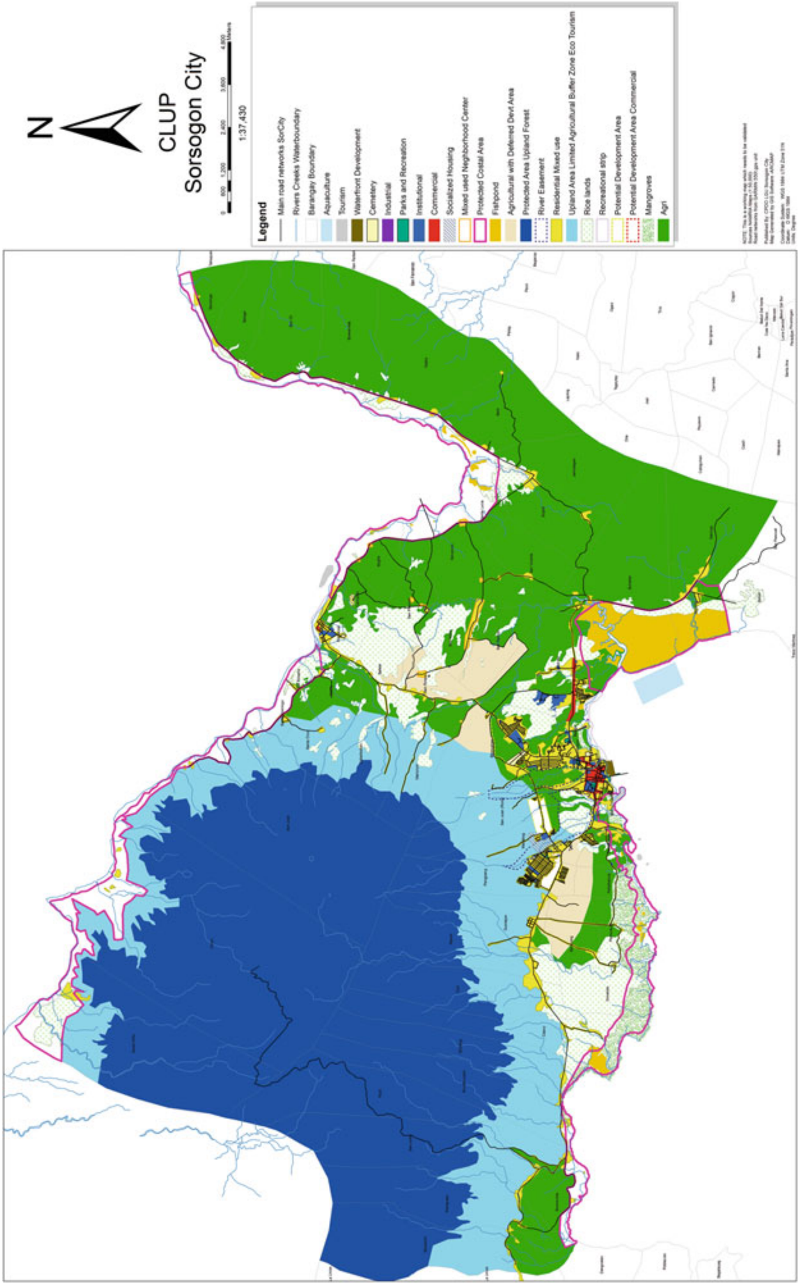

Fig. 12 New CLUP map of Sorsogon City (Source: Sorsogon City Government)

The V&AA hazard maps served as inputs in the review of the existing CLUP and CDP. Workshops among relevant city government officials, technical experts, barangay officials, and representatives from national government agencies and nongovernmental organizations were held to propose revisions in the two major local development plans. Sectoral consultations in the areas of environmental management and livelihood were conducted in November and December 2010 to refine the situational analyses. In addition, members of the local legislative council were briefed in February 2011 on its role in the formulation of the CLUP and CDP.

In a multi-stakeholder workshop on mainstreaming CCA and DRR in CLUP and CDP in March 2011, the participants identified four policy zones – areas which will be regulated and planned by the city for CCA and DRR through the CDP (Fig. 11). These areas, with the corresponding level of risks, are:

1. Coastal/built-up/hazard prone
2. Inland/agricultural/low risk
3. Upland/agri-forest/medium risk
4. Upland/protected forest/high risk

As a result of the formulation of the four policy zones, the city government, with approval from its legislatives council, decided to change the city vision. The new city vision is “A model city in CC and disaster risk resiliency with a contented, empowered and values oriented society that pursues socio-economic developments within the limit of nature thru genuine commitment to good governance.”

Aside from changing the city vision, a new CLUP map was drawn that incorporates findings from 12 socioeconomic maps (agriculture, commercial, built-up, infrastructure, informal settlers and settlement areas, rice, fishing grounds, urban areas, tourism, protected areas, minerals, and road networks) and four geographical feature maps (topographical, elevation, slope, and rivers). Refer to Fig. 12. In November 2011, a new CLUP was written which was submitted to the local legislative council for approval.

Conclusions

Generally, CCA and DRR are treated as conceptually and operationally distinct because of their spatial and temporal nuances. In the Philippines, the passages of two separate laws on CC and DRRM seemed to have sealed these so-called conceptual and operational divide. A closer scrutiny, however, reveals that they complement each other and they converge for the purpose of reducing risks to natural disasters and promote resilience. The national government has already laid down the guidelines for the integration of CCA and DRR in local development planning. Aided by these guidelines, Sorsogon City has shown that, given enough technical and financial assistance, the integrated CCA/DRR can be mainstreamed to local development plans, namely, CLUP and CDP.

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Making Adaptation Fit: Analysis of Joint Climate Change Adaptation Programs of the MDGF

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Abstract

Climate change adaptation governance is characterized by complexity and uncertainty, requiring harmonization across different sectors and scales as well as flexibility to respond to changing realities. International organizations have been increasingly involved in adaptation activities, particularly targeted at vulnerable populations, under established project management routines. However, to be effective, adaptation must be inherently context specific and dynamic to suit the ecological conditions and socioeconomic aspects of any given locale. This poses a dilemma: how can international organizations translate their often broadly defined global mandates, while simultaneously downscaling those mandates to suit the specific adaptation needs of given populations and ecosystems?

This research takes a case study approach to investigate the climate change adaptation experience of selected United Nations-led programs, investigating their responses to context-specific needs and highlighting the opportunities and challenges found in these experiences. The case study countries comprised of Bosnia and Herzegovina, China, Colombia, Egypt, Ethiopia, Jordan, Mauritania, Mozambique, Peru, and Turkey. Through the use of the 5C+ Protocol theoretical framework, the experiences of these country programs were compared to determine which factors were of greatest influence in successful program implementation.

The research concludes that the most significant challenges were: early inclusion of stakeholders to enable support and ownership of adaptation activities, meaningful participation by people at all levels in the identification of problems and solutions, and proper coordination of activities across affected sectors and governance levels. Paying specific attention to these challenges will allow for greater program effectiveness. However, incorporating such measures into adaptation must also include deliberate learning processes, to allow flexibility in response to potential nonlinearities of climate change.

Keywords

Climate change • Adaptive capacity • Learning • International institutions • 5C+ Protocol

Introduction

The Problem: Downscaling Complexity

Climate change adaptation is an emerging need worldwide because of the imminent threats of new climate regimes and the high levels of vulnerability of many socioeconomic groups and regions (IPCC 2007). In response, numerous international organizations have been planning and implementing climate change adaptation measures. Yet, adaptation to climate change is a complex governance challenge, characterized by uncertainty, long time frames, and nonlinearities. Adaptation normally requires coordination among a range of sectors, agencies, and interests, who traditionally may not have the working culture or framework for such collaboration – making not only the issues addressed but also the response methods novel and unprecedented in their complexity.

To be successful, climate change adaptation measures must take into account processes at multiple spatial and temporal scales and be inherently context specific to suit the ecological conditions, socioeconomic aspects, and institutional framework of any given locale (Cash et al. 2006). This poses a significant obstacle for international organizations. Such organizations usually have broadly defined global mandates, but the complexities of climate change adaptation require those mandates to be downscaled to suit the specific needs of individual populations and ecosystems (Hilde 2012; Wiechselgartner and Marandino 2012). It also raises the question of generality: how can practitioners learn from, generalize, and transfer lessons learned in different contexts in a way that is relevant elsewhere?

With these questions in mind, the aim of this research was to investigate how international organizations, such as the United Nations (UN), might most effectively apply their broadly defined global mandates by addressing specific local adaptation needs. Using a case study approach and a common analytical framework, this chapter first provides an assessment of the programmatic ability to respond to context-specific needs and, second, highlights the opportunities and challenges found within several such experiences. The case study in question focuses on the climate change adaptation experiences of selected Joint Programs (JPs) operating under the UN Millennium Development Goal Achievement Fund (MDGF). The lessons learned from the MDGF are intended for use by international organizations to inform the design of future adaptation-related interventions in the field.

The Case Study and Rationale

The MDGF was established by the UN with funding by the Spanish government to advance international efforts towards the achievement of the Millennium Development Goals (MDGs). All MDGF programming is implemented in the spirit of the UN "Delivering as One" initiative, which aims to improve harmonization of UN efforts in relevant member states (MDGF 2011a). MDGF programming was implemented in eight thematic windows, one for each of the MDGs. Several countries implemented programs in several windows. Within a country activities were implemented through a Joint Program (JP) that drew together UN agencies and national collaborators (MDGF 2011b). The MDGF case study looks in depth at the work of JPs in ten countries, including Bosnia and Herzegovina, China, Colombia, Egypt, Ethiopia, Jordan, Mauritania, Mozambique, Peru, and Turkey, that implemented activities between 2006 and 2012, under the MDGF environment and climate change window, related to MDG 7 to improve environmental sustainability. In each country, a variety of activities were undertaken, ranging from national policy mainstreaming to localized community-based climate change adaptation projects. Examples include a community-based forest management program

Fig. 1 MDGF case study countries (Image Source: Adapted from WikiCommons 2005)

in Mozambique, development of a national climate change and health adaptation strategy in Jordan, conservation and adaptation programs with indigenous populations in Colombia, and partnering with private sector industries in China (Fig. 1).

Data for the case study analysis are drawn directly from the specific experiences of the ten countries. Each JP is part of a global program, yet given the broad geographical scope and range of activities, the comparison among their experiences revealed different approaches to regional differentiation and contextualization. The rich diversity, due to the wide range of programs and experiences from the case study countries, allows the outcomes from our analysis to have generality, making them relevant in other contexts.

These ten MDGF programs were chosen as the basis for analysis for two primary reasons. First, the MDGF operates under the UN, which plays an important role globally in norm-setting and guiding country-level programs (UN 2008). The UN's international influence, particularly its leadership in global environmental governance, puts it at the forefront of emerging activities in the field of climate change. Second, the institutional framework of the MDGF has been set up to complement the UN's current efforts to "Deliver as One" – a direct response to institutional fragmentation and program inefficiency problems and an effort to improve harmonization of cross-sectoral activities (UNSGHLP 2006). The MDGF JPs implemented their activities jointly with several UN agencies, as well as government and community partners at both national and subnational levels. This institutional framework reflects the emerging role of collaborative environmental governance (CEG) and its importance in addressing complex problems such as climate change (Andresen 2001; Gunningham 2009).

Due to its potential for playing a norm-setting role through the UN, and manifestation of CEG, the lessons from the MDGF provide real value for emerging climate change adaptation interventions implemented through other international organizations.

Methodology

The Framework: 5C+ Protocol

An analytical framework, the 5C+ Protocol, was used to investigate how the JPs responded to context-specific needs, both opportunities and challenges faced through implementation. The research relied mostly on the use of a rich database of qualitative information, but quantitative information was also used where available and relevant. The experiences of the JPs were compared to each of several variables in the 5C+ Protocol, and relationships among those variables, to determine which were of greatest significance to the work of the JPs.

The 5C+ Protocol was developed as a modification of an original 5C Protocol framework by Najam (1995) that was based on a synthesis of literature on policy implementation, intended to help analyze and diagnose practical policy implementation measures. Najam identified five common variables – the "5Cs" – which he argued are interlinked explanatory variables essential for reviewing the effectiveness of policy implementation, particularly the "domestication" of international environmental measures (Najam 1995).

The 5C Protocol was modified by adding a sixth variable (thus, 5C + Protocol) to provide a common structure for analyzing the diverse experiences of the MDGF JPs. This framework was deemed appropriate for analysis of the MDGF case studies because it guides the investigation of several factors which influence practical implementation measures. As the 5C Protocol was developed for use in a general policy context, it was assumed that it also applies, with possible fine-tuning, to adaptation-related policies and activities. The framework also emphasizes how different variables, at various levels, interrelate and impact upon one another. The framework therefore has a dynamic element and simultaneously provides structure so the user does not get lost in the complexity of the issues studied. We addressed each of the six variables individually, and in relation to one another, for each of the case study countries (Table 1).

Critically, it is not only the variables themselves but also the relationships among them that provide insight into implementation effectiveness. Najam posited that in the 5C Protocol "the task is to catalog the strength and influence of each variable on specific implementation efforts as well as to identify critical linkages between them on the basis of their strengths and weaknesses, and, most importantly, their potential to enhance the effectiveness of the particular implementation process" (Najam 1995, p. 36).

The variables in the 5C+ Protocol are interlinked with one another (Fig. 2). This framework was used to analyze and compare the MDGF case study countries.

Data Collection and Analysis

Data for the study were collected using a variety of methods, including targeted literature reviews, participation in MDGF meetings and processes, and interviews.

Table 1 Variables and definitions associated with the 5C+ Protocol (Modified after Najam 1995)

Institutional corridor	The institutional environment through which policy and activities must travel, a variable that also provides the boundaries for specific implementation activities
Content	The content of a policy or program is threefold: what it sets out to do (i.e., goals), how it problematizes the issue (i.e., causal theory), and how it aims to solve the perceived problem (i.e., methods)
Commitment	The commitment of those entrusted with carrying out implementation, at various levels
Capacity	The capacity of implementers to carry out the changes desired by the policy, program, or activities; this includes both human and financial resources
Clients and coalitions	The groups or individuals whose interests are enhanced/threatened by the policy and/or program and the actions they take in response to its implementation either in support or opposition
Environmental conditions	The environmental characteristics (i.e., elements, state, dynamics, challenges, and opportunities) of a given geographical location

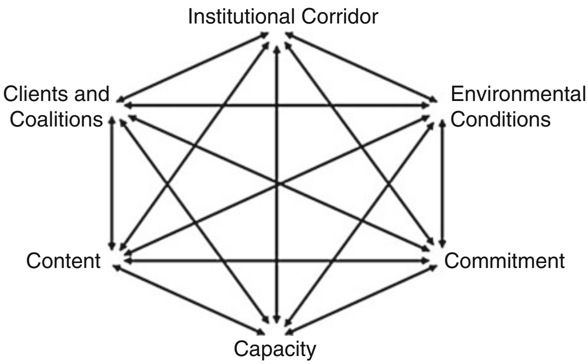

Fig. 2 5C+ protocol

Primary data were collected through in-depth interviews with selected JP representatives. The interviews were guided by the 5C+ Protocol and analyzed according to the variables shown in Fig. 2. The interviews were semi-structured, using open-ended questions, which alluded to each of the variables in tandem. Interviews took place both face-to-face and online. The interviews were transcribed and coded manually using the ATLAS.ti software. All data were coded according to the variables of the 5C+ Protocol then analyzed quantitatively, using total counts and co-occurrences to identify the strength of each variable and relationships to one another.

A second round of interviews was conducted with climate change adaptation experts not involved in MDGF, to validate and cross-check the results and conclusions of the primary interviews. Further, all results were compared to similar relevant findings in the literature and sharpened where warranted to ensure relevance for a wider audience.

Research Results

The primary interviews produced very rich qualitative data on the nature of the JPs and the challenges and opportunities experienced in implementation. The use of the theoretical framework and the coding software allowed these data to be analyzed quantitatively by use of total counts per variable and the co-occurrences (relationships) among the variables. Note that in this section, unless otherwise stated, all quotes come directly from the primary interviews.

Variable Counts

After transcription and coding of the interviews with representatives from the ten case study countries, the total count for each of the six variables in the framework was identified. The range of occurrences was 26–65 (Table 2).

It is clear from the aggregated results that the most commonly discussed variable, among all interviews, was clients and coalitions – the groups or individuals whose interests are enhanced/threatened by the policy and/or program and the actions they take in response to its implementation either in support or in opposition. This is unsurprising due to the crosscutting nature of the climate change field. The clients and coalitions variable was discussed by the JP representatives mostly with regard to the challenges they faced when dealing with competing and/or conflicting interests. The JPs faced various challenges when trying to understand the perspectives of different sectors and integrating these perspectives according to the aims of their various activities. For example, the Jordan JP representative stated that:

> If I say that we have been supported by all partners from all sides from the beginning, I wouldn't be telling the truth. We have different partners who are looking at the JP from different perspectives, so some of them see it as an opportunity to gain out of the JP, and some of them have seen it as an initiative that will make them lose some of their benefits and privileges.

Similar sentiments were repeated by each of the JPs interviewed. In all cases, they faced various camps of support and opposition, which had to be addressed in order to ensure implementation of the JP work.

Another common topic of discussion within the clients and coalitions variable was that of champions, i.e., finding the right individuals or groups who will showcase their support and through their convening power help the JP activities to gain the trust of potential ambivalent or opposition groups. These champions

Table 2 Total counts by variable

Clients and coalitions	65
Content	60
Institutional corridor	52
Commitment	40
Capacity	30
Environmental conditions	26

could be government or nongovernmental officials, the key point being that influential champions play a major role in a successful intervention. For example, the Mauritania JP representative emphasized in the interview how they utilized traditional leaders in their field activities:

> We use [non-state local leaders] as speakers, moderators or organizers. When they ask for a meeting, people will come. And when they speak, also the people listen to them.

From the perspective of the Ethiopia JP, it was a lack of champions that seemed to hinder their work at the national level:

> . . . you have to have champions – and champions mean having one or two key people in the policy process. . . Some of the issues we are dealing with are the allocation of national resources – the more you have a champion, that's why you get better access to the resource. I think that's one area where the JP didn't put in the list of priorities, but it should.

Other countries, for example, Peru, Mozambique, Jordan, China, and Bosnia and Herzegovina also highlighted the important role of champions within the governmental system. On the other hand, in some countries champions were explicitly nongovernmental. In Colombia, for example, tensions between the government and local communities made a local representative a more effective champion. It is clear, therefore, that while important in general, the selection of champions must also be highly sensitive to local opinions and realities.

Another frequently cited variable in the interviews with a total score of 60 was content, i.e., what a program sets out to do (its goals), how it problematizes the issue (causal theory), and how it aims to solve the perceived problem (methods).This variable was referenced during JP interviews most often in regard to the methods used to determine problems and solutions. For example, one of the main aims of the JPs was to ensure high levels of ownership on the part of domestic stakeholders (i.e., government officials at the national level or community members in field-level projects). With this aim in mind, the majority of JPs utilized participatory methods to engage local stakeholders. A parallel aim of such participation was to achieve better contextualization of the problems at hand. For example, the Turkey JP representative emphasized that:

> We tried to be participatory at maximum extent. . . When you talk about climate change adaptation, the national strategies or efforts are too generic. Because even between two villages, 5 km from each other, your adaptation efforts may change when it comes to climate change.

Another important point brought up repeatedly during the interviews with regard to content was the need to include livelihood activities and income generation options in all "solutions." The Mauritania JP representative, for example, stated that the environment had to be seen as "natural capital," so as to engage poor and vulnerable populations in the JP activities. Similar sentiments were described by the Mozambique JP representative:

> [We have] activities designed to help people to adapt to climate change, and also to help them to diversify their livelihoods – you can't really disassociate those two.

Particularly in field-level activities, the JPs were working mostly with vulnerable socioeconomic groups. Even at the national level where the JPs worked largely on mainstreaming climate change into national strategies and programs, there was a clear demand for economic benefits as part of any adaptation work. This need to integrate economic needs with environmental ones was very clearly emphasized throughout all of the JP interviews, showing that climate change adaptation cannot be achieved for environmental benefits alone; it must be seen as integrated with other pressing social and economic realities.

The third most common variable discussed in the interviews with a score of 52 was institutional corridor – the institutional environment through which policy and activities must travel, which also provides the boundaries for specific implementation activities. Related to the clients and coalitions variable discussed above, institutional corridor was most often brought up in relation to the crosscutting nature of the work and the difficulties faced in integrating several parties and interests, both within the UN and between UN and national government agencies. For example, the Turkey JP representative stated:

> It was very challenging putting all of them together in one team, because they have their own working cultures, their own administrative rules, plus no culture of working together.

Similar issues were raised by each of the JPs. Because climate change adaptation work requires the collaboration of several different sectors, it faces challenges not just on the administrative front but also in terms of culture. Many of these forms of behavior have been established over time and resilient to change even by a "joint" program. Often a series of behaviors and methods must be unlearned, and new ones learned to overcome traditional silo mentalities. An observation from the Ethiopia JP representative was:

> My assessment is that we have to do this several times before agencies can work together. The issue is sometimes mandates are overlapping, sometimes there is problems of synchronization... [all] this has an impact on the overall delivery of the program. There definitely needs to synchronize and harmonize a bit more, and if possible talk a little bit more to each other.

Another common thread raised by the JPs was the issue of institutional misfits. For example, several UN agencies were tasked to provide specialized input into the programs. Some of those agencies were nonresident (i.e., did not have permanent presence and staff within a country) and were asked to work alongside resident agencies. In some cases, it was clear only after implementation started that some agencies did not have the capacity or structure to allow them to operate effectively at the field level. For example, as revealed in the interview with the Mozambique JP representative:

> [As a non-resident agency] we're not really geared to delivering at the field, so it's not necessarily that people don't want to support, it's just the rules don't allow the level of flexibility that you need working in the field... I think there's a tension between the field and headquarters within the UN.

That same theme was apparent at more local levels when certain institutions were not capable of carrying out tasks, even if they were mandated to do so. In Mauritania, for example, this problem was apparent with respect to selected civil society organizations:

> . . . we call them ‘ONG cartables’ – it’s the NGO with an empty bag. . . as the country is poor, the civil society is not very strong, so maybe it’s the only NGO you find there and you will be supposed to work with them. There is no way you can work with someone else, but you know from the beginning that there is also a lack of capacity.

In some circumstances therefore, even though there is a need to integrate the expertise of different agencies or sectors, it is clear that there also is a need for realism to ensure the most appropriate partner is tasked with carrying out each activity, and if even the most qualified and appropriate partner lacks capacity, then capacity building must be a significant element of the work. This requires a careful balance between involving different areas of expertise and allowing actual implementation to be carried out by the most appropriate actors.

The other variables within the 5C+ framework were addressed less frequently, but revealed rich information. The commitment variable with a score of 40 was mostly clearly related to the JPs’ need to gather the right agencies and groups early in the process, in order to develop ownership of the activities. A failure to do so was often counterproductive to the work of the JPs. The capacity variable was often related to capacity building as an inbuilt component of the JPs. However, this variable was also referenced in regard to capacity-related realities that JPs faced on the ground, which required them to change their approach or alter certain implementation activities. The variable of environmental conditions occurred least frequently in the interviews with a score of 26. This is likely due to the close relationship between environmental conditions and content (i.e., the circumstances the JP itself was addressing). Notable within discussion of this variable, however, is that whenever environmental conditions were mentioned, the human dimension was always emphasized, as was the need for strengthening people’s adaptive capacities to deal with both rapidly changing and slowly changing environmental conditions.

Variable Relationships

The discussion above reveals that there is a degree of overlap among the variables. For example, the clients and coalitions variable was closely related to institutional corridor, with respect to the crosscutting nature of climate change adaptation work. The content variable and participatory methods was closely related to commitment, as an avenue for trying to encourage ownership of JP activities.

The relationships among variables (i.e., “co-occurrences” between codes) were quantitatively analyzed using ATLAS.ti version 7. Out of all the variables, there were 15 possible relationships. The number of co-occurrences (Table 3 below) helps understand the strength of these relationships.

Table 3 Codes co-occurrences

	Content	Institutional corridor	Commitment	Capacity	Clients and coalitions	Environmental conditions
Content		9	5	4	8	5
Institutional corridor	9		3	4	11	0
Commitment	5	3		3	19	1
Capacity	4	4	3		10	0
Clients and coalitions	8	11	19	10		2
Environmental conditions	5	0	1	0	2	

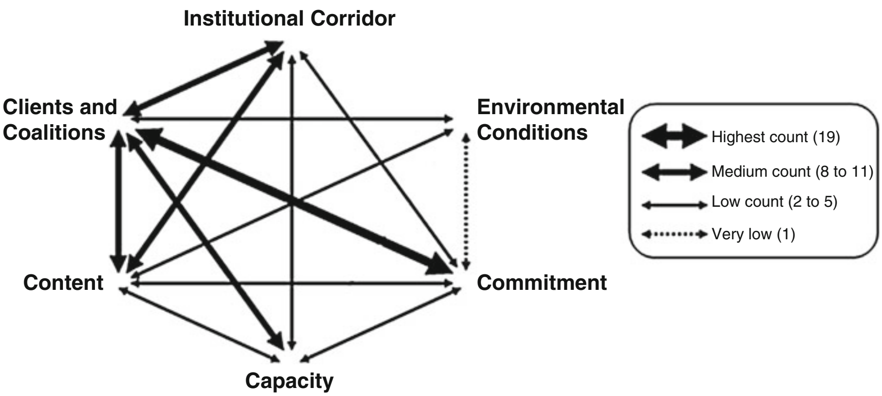

Fig. 3 Strength of factor relationships based on total count of co-occurrences

The co-occurrences can be expressed graphically (Fig. 3).The thickness of the lines indicates the relative strength of the relationship between two variables. The thickest line indicates the highest count (19), the medium-thickness line shows strength of 8–11, the thinnest lines indicate strength of 2–5, and the dotted line indicates the weak relationship of only 1. The absence of a line indicates that there was no mention of a relationship (0 count) between variables.

Based on the raw co-occurrences therefore, it can be seen that the strongest interrelationship is between clients and coalitions and commitment. To see whether this relationship strength remained true for all case study countries, another dimension of analysis was added to show the distribution of the relationships. The combined total variable counts, the level of co-occurrences, as well as the country distribution of the relationships are plotted in Fig. 4. The darkest blue line shows that the relationship occurred in all of the case study countries, while the lighter blue shows a lower level of occurrence in the case study countries. The relationship between clients and coalitions and commitment remains the strongest, in all dimensions of the analysis.

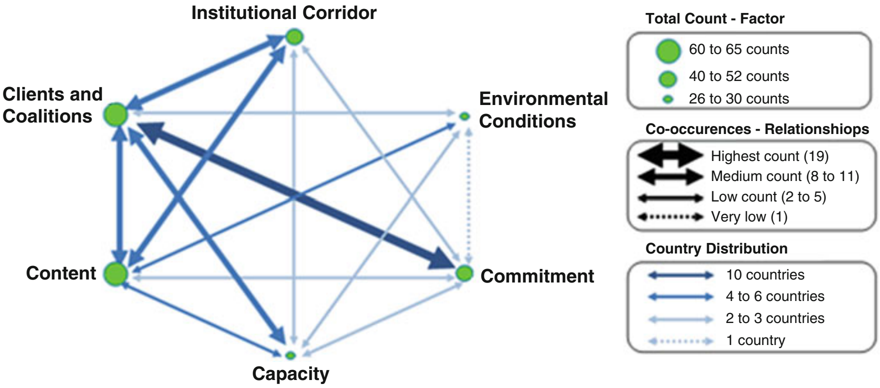

Fig. 4 Combined counts, relationships, and country distribution

The previous section revealed how the variables clients and coalitions and commitment were related strongly to the crosscutting nature of climate change work; it also demonstrated the importance of ownership and champions. Based on the experiences of the MDGF JPs, it is clear that the ability to include clients (i.e., targeted beneficiaries of a program) from the onset is necessary, not only to correctly identify needs and responses but mostly to garner their support for program aims and intentions. Getting the beneficiaries "on board" is also a key avenue through which positive coalitions can be built. Thus, it can be seen that both ownership and sustainability of program interventions are interconnected with the commitment and the clients and coalitions variables. This point was also strongly raised in various arenas outside of the JP interviews, including additional materials and discussions with the MDGF representatives (e.g., progress and evaluation reports, regular online "Weeks in Focus," and meetings in Kenya and Ecuador).

The relationship between commitment and clients and coalitions is also an important consideration when downscaling an intervention from a broad, global mandate to a more specific national or subnational program. If people with more localized responsibilities – both clients and potential coalitions – are not involved early and in a meaningful way, they are only given the possibility to react to a strategy and not have significant influence on design and execution of activities (Deri A. Independent consultant specialized on capacity development, including the role of learning and knowledge systems in resilience and adaptive capacity, "Personal interview," online, 6 May 2012). Similar points were also raised by Swanson et al. (2004) and Mitchell et al. (2006), who argued for the early inclusion of program participants. In fact, stakeholders should be involved in a process of "coproduction of knowledge" (Mitchell et al. 2006, p. 19), and not just be passive recipients, in order to ensure relevance of and commitment to program goals. Without this, it is not surprising if commitment or ownership is weak or nonexistent; as ownership must derive from a process of involvement, it cannot be simply superimposed at a later stage externally. This finding, of course, is not specific to adaptation, but given the highly contextual nature of this work, it is not surprising to find it particularly important.

Champions, on the other hand, are not only important for showcasing commitment but also for gaining support of other groups (i.e., forging partnerships and developing supportive coalitions with those who may have been external to the initial process). An inability to develop a sense of commitment to and identify a champion for a program's cause can be counterproductive by allowing negative coalitions to emerge among those who have an interest in blocking certain processes. There is therefore a cautionary tale to be told in that the relationship between clients and coalitions and commitment must be considered from the outset when planning or designing a program. This is particularly pertinent for issues of climate change adaptation, which are often crosscutting and likely to affect and be affected by various sectors and groups, at multiple levels of influence (Bulkeley and Newell 2010).

This linkage between commitment and clients and coalitions is intuitive and was hypothesized by Najam in his discussion of the clients and coalitions variable: "... with regards to commitment, the linkages are likely to be the strongest" (Najam 1995 p. 54). Thus, it can be seen that these variables have a very strong influence on determining the nature of each other, even outside of the specific experience of the MDGF JPs.

Another striking relationship with the clients and coalitions variable is that of institutional corridor. This relationship is characterized by the identification (either prior to or during the JP implementation) of clients and coalitions within the existing institutional framework, who could either support or actively block the JP processes. For example, at the national level, the ways in which the JP worked through the institutional framework could create blocking coalitions, by either failing to take some parties into account or by not including them in JP processes. On the other hand, actively involving key actors within the existing institutional framework often was deemed positive not only for the duration of the program but also for the sustainability of program interventions. An example of this was provided by the Ethiopia JP. In this case, although the JP had a limited impact on the policy level, it was reported that because all program activities were carried out through the conduit and preexisting framework of the Ministry of Environment, the work begun by the JP would still be carried through beyond the formal life span of the MDGF. Hence, by institutionalizing the aims of the JP within an existing framework, the clients of the program formed a supportive "advocacy" coalition (Sotirov and Memmler 2012).

The relationship between clients and coalitions and institutional corridor further highlights the comparative advantages of different institutional frameworks. In the majority of JPs, for example, particular activities were implemented by those UN and government agencies that had a specialized advantage in the activity (e.g., the Food and Agriculture Organization carried out agricultural activities, while the World Health Organization carried out health-related activities). Looking at external partnerships, however, in a number of instances, nongovernmental organizations (NGOs) or community-based organizations were deemed more appropriate for carrying out specific activities because their institutional framework was a better fit. In some cases, JP representatives commented that they had failed to capitalize on such positive external coalitions.

It is clear that institutional framework can greatly affect the types of activities that can be carried out, as well as their appropriateness to the specific problem at hand. This issue of institutional fit, and matching the correct institutional form with function, has been raised as an important point in the literature on institutional relevance for adequately addressing environmental concerns (Young 2002). In certain circumstances, a conscious choice must be made as to which institutional contexts are the best fit for certain activities. This may require delegation of different roles and responsibilities to external partners of a different institutional form where their form is deemed to be better suited to the task at hand (i.e., coalitions or clients).

The relationship between institutional corridor and clients and coalitions can also extend to include the capacity variable. For example, at the local level, the existing institutional framework and capacity levels of civil society and/or government determined which clients and/or coalitions were brought into the JP work. For example, in Bosnia and Herzegovina, high levels of civil society capacity allowed the JP to select NGOs that could actively carry out the work required and garner the necessary support for the work to go through. In contrast, the communities in which the Mauritania JP worked often had low capacity levels, which could have led to existing NGOs having a monopolistic effect on the selection of JP activities. These examples show a complex relationship in which capacity levels, clients and coalitions, and institutional corridor can impact each other. This is a particularly important point for those UN agencies that do not themselves have strong implementing capacity in a given country. These agencies by definition must rely on partners with reliable capacity to deliver.

A further significant relationship is between capacity and clients and coalitions. This relationship was highlighted by Najam, who stated that "… the linkage [of capacity] with clients and coalitions, although less obvious, is… critical" (Najam 1995, p. 51). In the identification and selection of clients and coalitions, for example, existing capacity levels can be a determining factor. As an example, targeted beneficiaries may be required to have specific capacity levels or a longer track record of relevant experience in order to facilitate program implementation. Moreover, the nature of capacities found among clients and coalitions may affect program delivery as well as support.

In the example of Bosnia and Herzegovina, for instance, local government activities were facilitated largely through select municipalities who already had high capacities and could spread their own work to others through a peer-review process. On the other hand, the Turkish JP experienced differentiated capacity levels. Despite the high capacities of technical staff with respect to climate change science, capacity at the level of political decision makers to understand climate change and impacts was very low. As a result, at the government decision-making level, the JP faced a great deal of opposition to the program in certain sectors. This was only remediated through targeted capacity development measures.

Lastly, a relatively strong relationship was seen between the institutional corridor and content variables. This relationship is based largely on how the different JPs designed their specific activities using the countries' existing institutional framework. For example, at the policy level of environmental mainstreaming, target clients and activities were identified using existing institutional frameworks. At the field level, the JPs often capitalized on existing institutional arrangements or frameworks – such as local government authorities or existing community-based organizations/cooperatives – and used these as channels to identify as well as deliver JP activities. Therefore, the linkage between institutional corridor and content derives mostly from the goal and causal theory levels; by targeting existing institutional arrangements, the JPs designed their activities according to existing gaps or opportunities. As mentioned above, utilization of existing institutional arrangements (both formal and informal), as opposed to investing in creating new institutions, seems a key factor in sustainability of program efforts.

Discussion

All of the analysis, including interviews with JP stakeholders as well as external climate change adaptation experts and cross-checking with the literature, has allowed the validation of the external relevance of the results of this research as well as the applicability of the 5C+ Protocol for analyzing climate change adaptation interventions.

Relevance

The multifaceted relationships described above resonate strongly with other studies. In particular, a study carried out by Cash et al. (2002) investigated key factors in transferring knowledge from environmental assessments into practical action. They highlighted three factors, salience, credibility, and legitimacy, as central to success (Cash et al. 2002):

- Salience – the relevance of information to decision making of various actors
- Credibility – how scientifically plausible an actor views information
- Legitimacy – if the process of knowledge creation is perceived as unbiased

All three of these factors have resonance to the key variables and relationships described above. Salience is linked closely to the capacity levels of actors receiving the information, clients and coalitions through early engagement, the realities of environmental conditions and points of comparison, as well as to the type of institutional frameworks at which these types of information are being directed. Credibility links closely to capacity, as well as the content of an information source (e.g., how an issue has been problematized and the process of this problematization). Legitimacy is linked clearly to content, clients and coalitions, as well as commitment.

The resonance of the interview results, both of isolated variables and their relationships to one another, with external sources, including expert opinion and research papers, highlights the utility of the results.

Utility and Lessons for the 5C+ Protocol

The 5C+ Protocol served as a valuable framework through which to investigate the experience of the JPs' work on climate change adaptation. The relationships among the different variables are complex and multifaceted; yet the lens of the 5C+ Protocol has allowed a systematic and guided analysis of these relationships. The chosen approach utilized both quantitative and qualitative data and analyses. This systematic information gathering and analysis serves as the basis for the conclusions and recommendations.

However, this research also revealed several lessons with regard to the limitations of the use of the 5C+ Protocol: identification of specific climate change adaptation practices and missing elements of time and learning.

The first limitation of the 5C+ Protocol is that, through its focus on institutional or procedural aspects of an intervention, it does not suggest specific climate change adaptation measures. The Protocol cannot be readily used to develop a set of best practices or guidelines related to specific types of climate change vulnerabilities or adaptation activities. Rather, the 5C+ Protocol-based analysis has greater utility in highlighting procedural aspects of climate change adaptation interventions, such as partnerships and participatory implementation. This may have applicability at broader climate change activities, which have to be inherently context specific (Schipper and Burton 2008). While it is often difficult to determine specific transferable activities (outputs) within climate change adaptation, particularly on shorter time scales, focusing on process elements/characteristics arguably has significant utility.

The second limitation of the 5C+ Protocol is that it does not include a built-in element of time and learning, which are critical components for climate change adaptation. An essential element of the management of complex and nonlinear issues such as climate change is the need for time frames that include adaptive management, revision of strategies, and corrective actions taken in response to changing circumstances (Swanson et al. 2004). Deliberately incorporating time as a variable would create the conditions for learning to take place (Siebenhüner 2002). However, this element of time will not automatically lead to learning if it is not a conscious part of an evaluation or assessment process (Siebenhüner and Arnold 2007). By not including a time component, the 5C+ Protocol remains limited in its ability to help facilitate learning processes. As it is, therefore, the 5C+ Protocol cannot be considered as an overall guiding framework for adaptive management in response to climate change. To do so, there must be specific recognition of this limitation.

To help facilitate learning, however, the 5C+ Protocol could be used as a common framework for a series of periodic assessments. The common framework can allow analysis of the current state (characterized by the variables and their relationships) and comparison of these states among different time periods. These comparisons can be used to track progress as well as highlight specific intervention needs. Therefore, organizations such as the UN could use the 5C+ Protocol as a quick analysis tool, prior, during, and after program implementation to identify specific challenges and opportunities related to the different variables, as well as identifying progress made in different areas (Bizikova L. Project Manager at International Institute for Sustainable Development, whose recent work is focused on adaptation to climate change, "Email communication," 22 May 2012). The common framework could also be used as a point of comparison among different, but similar, program implementers, helping to share experiences and methods to overcome procedural challenges.

Recommendations

This chapter shows that the implementation of national and subnational climate change adaptation activities, when derived from a general global mandate, faces specific challenges. A series of synthetic recommendations (Fig. 5) show a broad set of procedural measures that can aid international organizations such as the UN in addressing these challenges and effectively delivering context-specific climate change adaptation interventions.

However, to provide a more practical focus, there is a need to prioritize the most pertinent recommendations, based on the experience of the MDGF JPs and the results of this research. The most significant challenges we found were related to support and ownership of program activities, identification of most relevant problems and solutions, and coordination across sectors and governance levels. These challenges and possible measures to address them are summarized below:

- ***Support and ownership of program activities*** (clients and coalitions/ commitment):

  It is important to involve stakeholders early in the design of adaptation programs. Identifying and allowing for the meaningful participation of relevant stakeholders from an early stage increases commitment and ownership needed to carry out adaptation activities. As a specific element, the engagement of influential champions (individuals or groups) who can serve as program advocates is also important for rallying support from relevant clients and coalitions in the broader society.
- ***Identification of most relevant problems and solutions*** (content):

  This point also relates to the early inclusion of relevant stakeholders. By incorporating the inputs of program beneficiaries or partners early on – including the vulnerability problem identification and adaptation response in the design stage – there is a higher likelihood that problems and targeted activities for the intervention will focus on what really matters. This is particularly important for adaptation measures that are being "downscaled" based on higher-level templates or thinking and thus may not have full contextual information of the specific intervention area. It also raises the

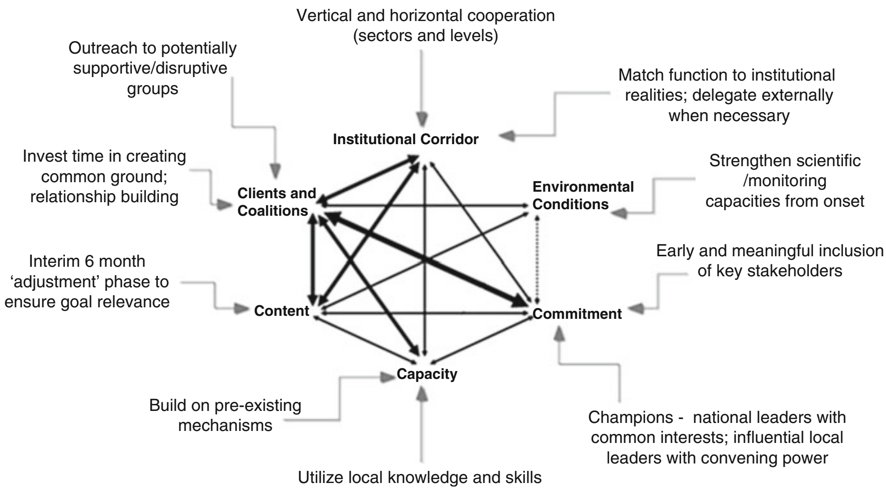

Fig. 5 Summary recommendations based on the 5C+ Protocol and JP experiences

potential for including the results of technical or scientific assessments as well as local knowledge at an early stage in the process. To facilitate this, we suggest incorporating an initial period for substantive stakeholder engagement at when adaptation programs are conceptualized, planned, evaluated, or adjusted. Additionally, later in the implementation stages, the work should have sufficient flexibility to incorporate the perspectives of significant stakeholders that may not have been included in initial stages, and in response to adaptation program results, as a form of institutional learning.

- ***Coordination across sectors and governance levels*** (institutional corridor):
The majority of JPs faced significant challenges in coordinating their work not only across different sectors (e.g., agriculture, water, health) but also between and across different types of governance and levels (e.g., national government ministries, UN agencies, and local communities). Addressing the potential for fragmentation is essential to ensure that competing interests and organizational mandates of diverse institutions do not compromise the program's ability to address adaptation needs. These needs, by definition, often cut across institutional, geographic, and other boundaries. To successfully manage issues as crosscutting as climate change adaptation, there must be a concerted effort to enhance coordination and harmonization and offer truly "joint" implementation of activities.

Remediation of these challenges will increase the probability of greater program effectiveness, building greater adaptive capacities, and ultimately a higher probability of long-term sustainability of climate change adaptation measures. However, to be effective, such adaptation measures must incorporate long-term planning and deliberate learning processes, to respond to the changing circumstances and potential nonlinearities associated with the effects of climate change.

Conclusion

It is notable that the JP operating framework and types of issues being addressed were in many circumstances the first of their kind in the countries where these programs were implemented. Jointly run climate change adaptation interventions are still young for the UN, and significant scope for learning remains. The experiences and lessons from the work of the JPs provide an important step towards improving the governance and management of climate change adaptation measures and enhancing effectiveness as well as building adaptive capacities of the most vulnerable.

However, this learning potential will not be achieved without targeted efforts. To be effective, adaptation measures must incorporate deliberate learning, to respond to the influence of various sectors, scales, and levels, their changing circumstances, and the nonlinearities associated with the effects of climate change (Berkhout et al. 2006). International organizations such as the UN must engage in intentional and effective organizational learning and adaptation processes, both to allow necessary adjustments within a program's life cycle and to ensure that the relevant and valuable lessons from specific program experiences can be accessed and used by others engaged in similar activities (Swanson et al. 2004; Swanson et al. 2010; Walker et al. 2001). Moreover, given that the field of climate change adaptation is young – and the danger of no or maladaptation has severe consequences, particularly for vulnerable populations – efforts towards such learning and information sharing should be enhanced.

Another cautionary point is related to the nature of prioritized adaptation activities. Adaptation to climate change is a long-term process, where building adaptive capacity (to respond to and thus reduce vulnerabilities) in the face of climate change is key. Climate change adaptation may require societies to respond/adapt to often completely new and hard-to-predict extreme events or "surprises" (Patt 1997). In such cases, following the traditional project cycles of development interventions is an ill fit. In part, the issue is that projects are often too short – generally not over 3–4 years and typically much shorter. Building real adaptive capacity often requires deeper structural changes that take more time to conceptualize, establish, and put into practice, whether it involves new measures or integrating new measures into existing mechanisms. Projects by definition also tend to have tightly defined objectives and activities with limited maneuverability during the project life cycle if conditions change. While this is desirable from the project management and accountability point of view, it limits flexibility and learning within the project if new learning emerges or if conditions change. Such project designs and time frames limit the relevance, flexibility, and responsiveness of the work that effective climate change adaptation requires.

If international organizations such as the UN want to implement truly effective climate change adaptation interventions, they must adopt a more long-term view that incorporates flexible project design and budgeting requirements, geared specifically towards building adaptive *capacities* rather than just adaptation activities

(Folke et al. 2002). It may also require mechanisms that allow longer project life cycles, involving dynamic partnerships with other donors and participants from the public and private sector, considering the shifting modality of international development assistance. Having a longer-term view and involving additional partners may also require addressing the reality that adaptation activities cannot be restricted to climate change in a narrow sense of the term. While climate change is a significant new source of vulnerability, it is certainly not the only one. Climate vulnerability is often coupled with vulnerability due to other factors, and thus both for reasons of effectiveness and efficiency, adaptation responses should where possible also be integrated. Moving in this direction will require concerted efforts and time to design and implement adaptation measures based on principles of meaningful joint planning, participation, and thematic integration.

Adaptive, cross-scale and collaborative management approaches are key to ensuring that international organizations are able to address the complexities and urgency associated with climate change vulnerability and adaptation. However, an important challenge faced by international organizations such as the UN is the relevance of downscaling their global initiatives to suit localized needs. By its very nature, climate change adaptation requires a high level of context relevance and specificity. As such, it also requires international organizations to invest time and effort required to build relationships with beneficiaries and/or to forge strong relationships with key counterparts who may be a better fit for delivering such contextualized measures.

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Interviews

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Physical Damages Associated with Climate Change Impacts and the Need for Adaptation Actions in Latin America and the Caribbean

Walter Vergara, Ana R. Rios, Luis M. Galindo, and Joseluis Samaniego

Contents

This chapter is an excerpt from Vergara et al. (2013), a book where the topic is further developed. The views and opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the Inter-American Development Bank, its board of directors, the countries they represent, or of the WRI and ECLAC.

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Abstract

Changes in climate during this century will have broad impacts on human activities and ecosystems, and the likely consequences are of such a magnitude that the simultaneous need to adapt to the new climate conditions and to reduce the carbon footprint to prevent even further damage will likely become one of the main driving forces for the global community over the coming decades. We attempt to simultaneously address two main questions related to the climate change challenge for Latin America and the Caribbean. First, what are the key physical impacts and consequences of climate change? Second, what are the likely costs to the regional economies derived from these impacts? Results indicate that conservative annual damages are about US$100 billion by 2050 and the overall investment required to adapt is approximately one-fourth to one-sixth of the costs associated with those impacts. Rapid and decisive adaptation actions are urgent to reduce the magnitude of these effects although some irreversible damages would remain as adaptation measures do not generally result in the full restoration of lost natural and cultural capital.

Keywords

Climate change • Adaptation • Economic impacts • Latin America and the Caribbean

Introduction

The global average concentration of carbon dioxide (CO_2) in the atmosphere has increased considerably, rising from approximately 280 parts per million (ppm) in the late eighteenth century to 400 ppm in early 2014 (NOAA 2014). This trend is just below the most pessimistic scenario (A1FI) visualized by the Intergovernmental Panel on Climate Change (IPCC) in 2000 and might trigger climate feedback effects that are not well known (Ackerman and Stanton 2011). Scientific analyses indicate that a CO_2 atmospheric concentration of 450 ppm is consistent with a 2 °C increase in global temperature, relative to preindustrial levels.

The 2 °C threshold has been the basis behind efforts to stabilize climate conditions given that it is linked to the strong likelihood of "dangerous" changes in the climate (Schellnhuber 2009; IPCC 2014). Despite a degree of uncertainty regarding the future "business-as-usual" emission trajectory and climate sensitivity, there is a growing consensus that emissions need to be reduced to a level consistent with this guardrail to avoid further climate destabilization. Even if greenhouse gas (GHG) emissions are effectively reduced, consistent with the 2° guardrail, climate impacts are likely to affect the economies and natural resources of Latin America and the Caribbean (LAC). This is in large part because of the region's substantial but intrinsically fragile natural capital (which includes climate-sensitive ecosystems), geographic location, and vulnerable infrastructure. Adaptation responses to the impacts of a 2 °C temperature rise are therefore necessary and play a critical role in any regional climate strategy.

This chapter attempts to simultaneously address two main questions related to the climate change challenge for the region. First, what are the key physical impacts and consequences? Second, what are the costs to the regional economies derived from these impacts? For this purpose, the impacts of climate change are identified and their economic impact is quantified. Then, an overview of associated cost of adaptation measures is presented. Mitigation activities are also needed to avoid the dire projections of temperature rise above 2 °C; the analysis of these actions – although important – is beyond the scope of this study. For a comprehensive treatment of mitigation pathways in LAC, see Vergara et al. (2013).

Physical Impacts and Consequences

The physical impacts of climate change depend on atmospheric concentrations of GHG emissions and the capacity to adapt to these changes (Wilbanks et al. 2007). Mitigation and adaptation targets are thus interrelated – mitigation attenuates the risks of global climate change, whereas adaptation ameliorates specific impacts in a particular location. Some now consider a midcentury temperature increase of 2 °C over preindustrial levels to be virtually unavoidable (Hansen et al. 2012) unless drastic and immediate actions are undertaken. Climate change of this magnitude will significantly disrupt livelihoods, social conditions, and ecosystems (IPCC 2007). Some of the key physical consequences projected for the region follow.

Agriculture

The impacts of climate change on agriculture are expected to reduce food supply and increase food prices, with potentially negative impacts on income, food security, poverty, and nutrition (Ahmed et al. 2009; Nelson et al. 2009). As temperature, moisture, and rainfall patterns change, so will crop yields and the distribution of agricultural production (Dawson and Spannagle 2009). In the short run, yields of certain crops may increase or decrease in different areas, according to projected rainfall, temperature, and weather variations. For instance, yields might increase because of a CO_2 fertilization effect or more benign weather conditions (Nelson et al. 2010; Magrin et al. 2007; Seo and Mendelsohn 2008a, b, c; Mendelsohn and Dinar 2009). Over the longer term, LAC's agricultural output is anticipated to fall because of combined changes in rainfall patterns and soil conditions (ECLAC 2010; Tubiello et al. 2008; Mendelsohn and Dinar 2009).

Negative effects of climate change on crops in LAC could be significant and are expected to play a major role in the global food supply chain (Fernandes et al. 2012). In this study, the authors report that simple adaptation alternatives (e.g., improved varieties, change of sowing dates, and modest irrigation) are not sufficient to overcome the forecasted impacts of climate change which will account for US$32–54 billion annual reduction of agricultural exports in the region by 2050. These impacts, particularly in the context of a tight global food supply–demand balance, may also trigger other consequences including food market speculation and threats to food security.

Coastal and Marine Zones

LAC is particularly vulnerable to sea-level rise because of its extended coast, geomorphology, prevalence of coastal settlements, and value of coastal economic activities (Nicholls and Tol 2006; Sugiyama 2007). Sea-level rise and an increased frequency and severity of storm events will likely lead to greater coastal flooding and erosion, which may cause substantial property and infrastructure damage, ecosystem losses, and partial land loss (Suarez et al. 2005; Jacob et al. 2007; Williams et al. 2009). Estimated annual costs of a 1 m rise in sea level in the region are approximately US$19 billion (Dasgupta et al. 2007). Accumulated costs associated with this impact are around US$255 billion considering capital and net wetland losses in Latin America (Sugiyama 2007). Moreover, recent data by ECLAC (2012) show that this increase in sea level would affect approximately 6,700 km of roads in the region and at least 40 % of the population living in the coastal areas of Chile and Uruguay.

Sea-level rise is also increasing hydrostatic pressure on coastal freshwater aquifers, some of which play a critical role in water supply. For instance, measurements of conductivity in the San Andrés Islands (INAP 2012) indicate a long-term trend that, if continued, will eventually render the water supply unsuitable for human consumption. There is thus an urgent need for more significant contingency planning and adaptation efforts along coastlines.

Most corals are highly sensitive to changes in the environment; when stressed by rising temperatures, corals lose the symbiotic arrangements needed for photosynthesis, leading to bleaching and eventually death. Temperatures in the Caribbean are anticipated to reach threshold values that would lead to repeated bleaching and a collapse of the coral biome. This is of great importance since significant economic impacts and losses in biodiversity could occur as coral reefs are the most biologically diverse marine ecosystem with more than 25 % of all marine species. For example, annual cost derived from losing half of the coral cover in the Caribbean has been estimated at about US$7 billion (Vergara 2009).

The recent increase in land-falling hurricanes has been associated with a broader increase in average tropical cyclone wind speeds as sea-surface temperature rises (Curry et al. 2009), and hurricanes are intensifying globally (Emanuel 2005; Webster et al. 2005). Expected annual economic impacts associated with intensified hurricane activity by 2050 are in the US$5 billion range (Toba 2009), while damages from tropical cyclones are projected at about US$110 billion–US$149 billion for 2021–2025 (Curry et al. 2009).

Health

Main health threats associated with climate change in Latin America are malaria, dengue, cholera, and heat stress (Githeko and Woodward 2003). Increased temperature and precipitation will expose the region to a higher transmission risk of malaria (Magrin et al. 2007), whereas changes in geographical transmission limits

(Hales et al. 2002) and distribution of vector-borne diseases would favor the incidence of dengue. Moreover, LAC is expected to suffer from a higher prevalence of diarrheal diseases and malnutrition with an associated annual health burden of around US$1.3 billion by 2030 (see Table 1).

Hydrology

Hydrological regimes would be affected by changes in average conditions and increases in the amplitude and frequency of extreme precipitation events. The hydrology of major rivers in the Amazon Basin is projected to become less stable with probabilities of higher peaks and lower nodes (Vergara and Scholz 2011), and intensification of flooding in the Grijalva Basin in Mexico has caused damages valued at 30 % of the region's GDP in 2007 (CONAGUA 2009). Less stable hydrological regimes in major basins will lower firm capacities in hydropower production and result in the need for additional storage to maintain reliability in water supplies. For Brazil, these unstable conditions would reduce the firm-guaranteed minimum capacity of hydropower reservoirs by around 30 % (De Lucena et al. 2010), equivalent to an estimated yearly cost of US$18 billion (Table 1).

Visible impacts of the changes caused by new climate patterns are evident in the Andes: warming temperatures have caused rapid retreat of glaciated areas, and variability and extremes in weather conditions have started to affect Andean ecosystems and human activities. Black carbon emissions within the region from land clearance, biomass burning, and other sources like transportation may also be contributing to glacier retreat (Simões and Evangelista 2012; Vergara and Rios 2013) and are changing the albedo in the Antarctic Peninsula (Pereira et al. 2006). During 1970–2002, the area of tropical glaciers in the Andes decreased by more than 15 % (Kaser and Osmaston 2002). This phenomenon has significant consequences. For example, glacier retreat is estimated to lead to an annual incremental cost between US$212 million and US$1.5 billion for the generation of energy in Peru (Vergara et al. 2007), and the city of Quito would require an additional investment of US$100 million over the next 20 years to guarantee its future water supply (Vergara et al. 2007).

Potential Rainforest Dieback

Current climate trends and human-induced deforestation may be transforming the structure and behavior of the Amazon rainforest (Phillips et al. 2009). Any drastic changes in the ground cover of the Amazon Basin will modify the provision of a variety of ecosystem services such as carbon storage and sequestration, soil fertility, and water supply and affect local and regional climate. The probability of a substantial reduction in Amazon forest biomass due to climate change, or Amazon forest dieback, has been the focus of a growing body of research

Table 1 Estimates of annual damages from some key physical impacts by 2050

Impact	Area	Projected annual costs[a] (2005 billion US$)	Projected cumulative costs	Source
Loss in net export agricultural revenues: wheat, soybean, maize, and rice	LAC	26–44		Fernandes et al. 2012[b]
Sea-level rise (1 m)	LAC	22		Dasgupta et al. 2007[c]
Coral bleaching	Caribbean	8–11		Vergara et al. 2009[d]
Intensification and frequency increase of extreme weather events	CARICOM	5	110–149 for 2021–2025	Toba 2009[e]
	Mexico's Gulf Coast, Central America, and the Caribbean			Curry et al. 2009[f]
Health (increase in incident cases of diarrhea and malnutrition)	LAC	1		Ebi 2008[g]
Amazon dieback	Latin America	4–8		Authors' estimation[h]
Glacier retreat	Peru	1		Vergara et al. 2007[i]
Loss of ecosystem services	Latin America		36	Authors' estimation[j]
Hydropower generation	Brazil	18		Authors' estimation[k]
Estimated total		85–110		
Percent LAC GDP[l]		1.8–2.4		

[a]Estimated total must be considered a conservative range of values with the following caveats: (a) estimations are gathered from different studies with varying methodologies, assumptions, and uncertainties; (b) many costs are only partially presented, and others are difficult to estimate; and (c) nonmonetary costs are excluded. The CPI is used to convert costs to 2005 US dollars (Bureau of Labor Statistics). When information was not available, costs were assumed to be reported in US dollars of the year in which the study was published

[l]2010 GDP measured in 2005 dollars

[b]Projected loss in net export revenues in 2050

[c]Impact on GDP observed when a 1 m rise in sea level is reached

[d]Estimation derived from losing 90 % of coral cover under SRES A1B scenario. Includes lost value of coastal protection, fisheries, tourism, and biochemicals

[e]Considers impacts of "climate disasters" (floods, droughts, and windstorms) on agricultural production, human health, tourism, government, and GDP loss

[f]2007 US dollars. Projected costs correspond to tropical cyclones during 2020–2025, scenario A1 (lower range) and scenario B2 (upper range)

[g]Cost in 2030 under a scenario assuming (i) stabilization of emissions at 550 ppm of CO_2e by 2170 and (ii) annual cases and treatment costs remain constant

[h]Projected cost in 2100 obtained from TEEB (2010). These costs consider ecosystem services in terms of carbon storage and sequestration, agricultural productivity, hydropower generation, sustainable timber harvest, reduced siltation in hydropower reservoirs, commercially viable fish populations, subsistence life styles, and improvements in quality of life. Reduction in rainforest biome obtained from Vergara and Scholz (2011). Note that many of the services provided by the biome are transnational and global services and as such their valuations are not considered

[i]Incremental cost for the power sector based on rationing cost

[j]Economic impact assuming a doubling of CO_2, estimated in 2000 dollars. Authors' elaboration based on data from Leemans (1989)

[k]Value estimated based on the reduction in firm power hydroelectric generation in 2035 under scenario B2 reported by De Lucena et al. (2010), hydropower generation from the Brazilian National System Operator (ONS), and the cost of rationing from Mauerer et al. (2005)

(Malhi and Phillips 2004; Malhi et al. 2006; Phillips et al. 2009; Nepstad et al. 2006; Brando et al. 2008; Saleska et al. 2007; Cox et al. 2004; Sitch et al. 2008). While individual results vary, climate change is expected to have a negative effect on the rainforest biome in the Amazon. In economic terms, a partial estimate of this impact is about US$4–9 billion annually.

Ecosystems and Biodiversity

In addition to impacts affecting human activities and infrastructure, climate change will alter natural ecosystems and species. Climate change is accelerating the natural process of biodiversity modifications affecting vegetation, composition of ecosystems, and distribution and migration of various animal species (IPCC 2001, 2007). Changes in air temperature and the onset of seasonal variations will affect the capacity of species to migrate and the composition of the habitats on which they depend in their well-timed routes (Robinson et al. 2005). Although assigning monetary values to ecosystem functions entails significant methodological difficulties (Arrow et al. 1993; Heal 2000; Spash and Vatn 2006), an attempt employing meta-analysis reports a net annual economic loss of US$36.5 billion as a consequence of climate change impacts in Latin American ecosystems (see Table 1).

Irreversible effects on biodiversity are projected, and climate change may also produce significant feedback effects that cannot at this time be properly valued or understood. The impacts of irreversible harm to biodiversity are more than merely an economic matter; they have significant ethical implications. Many of these effects represent committed changes that will not be easily reversed and will continue over time, even if reductions in the rate of emissions are secured.

Estimate of Damage from Physical Impacts

Based on the information presented in the previous section, the aggregated value of the projected annual economic damages in LAC resulting from some of the major physical impacts associated with this unavoidable 2 °C increase over preindustrial levels is summarized in Table 1. Damages are expected to grow gradually, reaching approximately US$85–110 billion per year by 2050 (measured in 2005 US dollars). Several aspects must be taken into account when assessing the severity of this economic impact including, among others:

– Reported amounts are a conservative estimate of annual damages; these are not comprehensive and include partial estimates in terms of impacts and geographical coverage.
– Impacts whose economic valuation is challenging due to data limitations and/or difficulties in assigning monetary values have been excluded (e.g., damages to biodiversity, change in the stock of natural resources, biome collapse, irretrievable damages in natural capital, and cultural and social services).
– Effects of climate change accumulate over time – damage is already occurring and will intensify as extreme events become more frequent or intense, and gradual changes like temperature increases take effect.
– This is a simplified analysis where adaptation does not take place. People, households, economic entities, and other businesses will adjust in view of climatic changes and continuous losses. But unplanned adaptation and learning from losses is still costly and could be preempted by adaptation programs and measures that increase resilience.

A Four-Degree Anomaly

Costs of physical consequences and estimates of adaptation costs refer generally to a trajectory consistent with a 2 ºC temperature anomaly. However, the actual path of emissions is closer to scenario A1FI, associated with an atmospheric concentration of CO_2 above 800 ppm and a forecasted 4 °C increase in global temperature. Under this trend, the impacts of climate change will escalate and associated adaptation costs would increase. The changes induced in a 4 °C future would likely be long lasting, even if emission patterns could be quickly reversed.

Overall Adaptation Costs

Table 2 presents adaptation costs for LAC reported by UNFCCC (2007), World Bank (2010), and Agrawala et al. (2010). These studies have significant limitations and uncertainties leading to estimates that are difficult to compare because dissimilarities in methodologies, sectors, time spans, and adaptation measures are considered. Nonetheless, regardless of the value considered, adaptation costs are an order of magnitude lower than the costs of physical damages. This finding highlights the importance of deploying efforts to adapt.

Adaptation has the potential not only to reduce the net impact of climate consequences but also to support the overall sustainability of development in LAC. Whereas development needs are immediate, the problems created by climate

Table 2 Adaptation cost estimates (billions of US$)

UNFCCC (2007)		World Bank (2010)			Agrawala et al. (2010) AD-WITCH	
Scenario	B1-A1B	Scenario	NCAR	CSIRO	Scenario	Doubling CO_2
Year	2030	Year	2050	2050		
		Agriculture	1.20	1.30	Water in agriculture (irrigation)	4.30
		Fisheries	0.18–0.35	0.18–0.35	–	–
Water supply	23.00	Water supply	5.50	3.20	Water infrastructure costs in other vulnerable countries	1.80
Coastal zones	0.57–0.68	Coastal zones	11.7[a]	11.7[a]	Coastal protection costs	7.75
		Extreme weather events	1.3	0.70	Early warning systems	5.00
					Investment in climate-proof settlements	5.90
Infrastructure	0.40–1.72	Infrastructure	3.5	1.70	Cooling expenditure	2.0
		Human health	0.00	0.00	Disease treatment costs	5.72
					Adaptation R&D	0.07
		Total	21.50	16.80	Total	27.70

Source: UNFCCC (2007), World Bank (2010), and Agrawala et al. (2010)
Notes: *NCAR* National Center for Atmospheric Research, wettest scenario; *CSIRO* Commonwealth Scientific and Industrial Research Organisation, driest scenario
[a]Medium rise in sea-level scenario (28.5 cm above 1990 levels in 2050). UNFCCC (2007) estimates are for Latin America only

change – though substantial – are perceived as gradual, far-off, and (in some cases) uncertain. But a lack of action on adaptation will generate more development needs in the future. Rather than being viewed as separate from development (Leary et al. 2008), adaptation should thus be seen as an integral component of this process. Unless addressed, climate change impacts will represent a heavy burden to development agendas in the region.

Conclusions

LAC is particularly vulnerable to the observed and projected impacts of climate change mainly because of its geographic location, distribution of population, infrastructure, and reliance on fragile natural resources for economic activities and livelihoods. Key impacts include the collapse of a significant portion of the coral biome in the Caribbean, disappearance of most glaciers under 5,000 m in the tropical Andes, reductions in agricultural yields, increased flooding of coastal zones, higher exposure to tropical diseases, destabilization of the hydrological cycle in major basins, and intensification of extreme weather events. Many of these changes are considered to be not only inevitable but also irreversible; climate change will therefore continue to adversely affect the region over the long term.

Economic damages caused by physical impacts associated with the likely rise of 2 °C over preindustrial levels are projected to gradually increase and reach a conservative annual estimate of US$85–110 billion by 2050. These impacts are already taking place and will intensify as temperatures increase. Losses of this extent will undermine the region's prospects for improvements in quality of life, by significantly limiting development options and restricting access to natural resources and ecosystem services. Economic resources, already inadequate to meet competing demands, will be further strained.

On the other hand, overall adaptation requirements represent approximately one-fourth to one-sixth of the expected damages. Rapid and decisive adaptation actions are thus urgent to ameliorate some of the physical and socioeconomic impacts of climate change. Despite the implementation of these measures, however, some irreversible damages would remain as adaptation does not generally result in the restoration of lost natural and cultural capital.

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Strategic Military Geography: Climate Change Adaptation and the Military

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Abstract

This chapter explores climate change impacts on defense forces (militaries) and suggests ways for them to respond. It considers general military capacity to become more involved in climate adaptation, proposes some best practices, and articulates a decision framework for action. We have developed a framework for capture and analysis of the military role within broader climate adaptation. The Strategic Military Geography (SMG) Framework is a decision framework that allows collaborative exploration of the relationship between climate change impacts and military activities. SMG employs systemic action research, which integrates systems thinking, participatory action research, and triple-loop learning to address the complex, interlinked issues relating to global change, including climate change. It was found that defense forces can play a significant role in climate adaptation, in armed conflict situations, and in military operations other than war, such as humanitarian assistance and disaster relief. For example, military personnel are regularly involved as responders to natural disasters and often play a central role in reconstruction. Practical ways that defense forces can build climate adaptiveness include incorporation of projected change and associated uncertainty into preparedness (readiness) planning, improved forecasting, regional and whole-of-government engagement on climate adaptation, and building energy sustainability that reduces carbon emissions. The framework presented supports system-wide long-term planning, fosters greater dialogue between critical stakeholders, and enables transfer of learning between defense forces and other organizations.

Keywords

Defense • Strategic military geography • Climate change • Adaptation • Security • Decision framework

Introduction

This chapter draws on an Australian Defence study of global change impacts and engagement with other defense and national security organizations including military forces. Defense forces have no choice but to take an interest in adaptation to physical environmental and geographical change. The Australian strategic policy, for example, has formally identified climate change as a threat to national security and homeland infrastructure since at least 2008 (Thomas 2013). Regardless of cultural or philosophical views on the role of military organizations, a great many of them will be central players in climate change adaptation and response.

Climate change, and more broadly global change, is often characterized as a complex, evolving problem. To address such problems, holistic and systemic approaches are advocated (Commonwealth of Australia 2007). One way to contextualize climate change impacts into military organizations is via the construct of

Strategic Military Geography (SMG). The SMG Framework draws on systemic methods of inquiry and learning to explore and take action in a large, diverse military organization. SMG provides ways to frame issues in a military context and collaboratively explore the relationships between global change, including climate change adaptation, and military organizations.

Using the SMG framework has facilitated identification of priority issues for the military in four key areas. These are the operating environment, mission profiles (tasking), supporting infrastructure, and business continuity. Business continuity in this context is a holistic management process that identifies potential impacts that threaten an organization and provides a framework for building resilience and the capability for an effective response that safeguards its critical functions. This framing and analysis has aided the Australian Defence Organisation to begin to prepare for and adapt to global change, including climate change.

The Strategic Context of Climate Change

Military organizations have a keen interest in climate change adaptation. The US Navy, in particular, has arguably been at the forefront of raising awareness and responding to climate change implications for defense and national security (US Navy 2010). Other militaries active in climate adaptation include the UK Ministry of Defence, Indonesia, New Zealand, the Maldives, Bangladesh, Papua New Guinea, and NATO members. In 2010, for example, NATO secretary general Anders Fogh Rasmussen wrote: "Climate change presents security challenges of a magnitude and a complexity we have never seen before. We must be prepared for them" (Rasmussen 2010).

A literature review by Thomas (2013) shows that a range of defense and security scholars have explored the implications of climate change for military forces, particularly in terms of their future capabilities, tasking, and ability to support their nations. Serving and retired military personnel have also been active in raising awareness and talking about the implications for defense and national security (Barrie 2013). This has led to some debate more broadly about the "securitization" of climate change and some suspicion of military intentions. The alternative view is "normalization" of the military as an instrument of state in achieving national goals including greenhouse gas reductions and climate change adaptation (Thomas 2013).

In the Australian SMG study, the latter view has been taken, that is, that defense forces or militaries – as large employers, as a key implementer of national security policy, and as significant purchasers, custodians, and users of government assets – can legitimately play a role in climate change adaptation efforts. In Australian security discourse, the strategic risks of climate change have been identified in academic and think-tank literature as well as formal strategic policy since at least 2006 (Thomas 2012).

The First National Security Statement to the Australian Parliament, published in 2008, described climate change as a "new and emerging challenge" and one that represented a "most fundamental national security challenge." This Statement also called for climate change threats to be formally incorporated into Australia's national security policy and analysis process (Rudd 2008).

The 2009 *Defence White Paper: Force 2030* subsequently crystallized two major security implications of climate change. The first was that climate change may exacerbate the severity and frequency of natural disasters, thereby requiring increased military support to humanitarian assistance and disaster relief (HADR) operations. The second described how climate change may exacerbate existing precursors to conflict whereby vulnerable states (with limited capacity to respond) may dissolve into violent conflict, thus triggering military intervention as a "stabilizing" force. Climate change here is seen as a "threat multiplier" rather than a distinct driver of hostilities (Department of Defence 2009).

More recent guidance from the 2013 *National Security Strategy* and the 2013 *Defence White Paper* has reiterated the strategic risks of climate change (Department of Defence 2013). Related literature including from the Australian Strategic Policy Institute and internal analyses have identified a range of other areas in which climate change may affect the Australian Defence Force.

Investigation, Decision, and Action Framework

To identify and understand climate, and other global, change impacts on military forces, a decision support framework called Strategic Military Geography (SMG) has been developed. The SMG framework employs systemic action research as its main methodology. This methodology integrates systems thinking, participatory action research, and triple-loop learning as these conceptual approaches are useful for investigating complex, multifaceted issues where there is limited or incomplete knowledge of all the affecting factors (Bawden 1990).

Implicit in systemic action research is an assumption that people in a given field of activity are attempting to adapt themselves and their environments in the face of change. Burns (2009) describes systemic action research as:

> The Systemic aspect is crucial because any action taken will be affected by underlying patterns and social norms; complex power relationships between a range of stakeholders; activities that may seem peripheral and beyond the immediate operating environment, non-linear effects of multiple linear interactions and different, sometimes contradictory, impacts at different levels of the system under review.

The entry points where possibilities for change can occur, and the "tipping points" which support sustainable phase change, are often invisible in typical research analysis or organizational development practices.

In this methodology, systems are broadly encompassing, affecting the whole of life. That is, systems can be an understanding of the way the world is, a way of thinking about the world, an approach to dealing with problems, a set of methods and techniques, or all of these. A system is defined as a set of elements connected in some way to form an identifiable whole. The properties of this whole emerge as a result of the relationships between the component parts, rather than being the sum of the properties of the parts (Bawden 1990).

Action is fundamental because action learning provides insights and practices not generated by other types of learning. New opportunities and entry points for development or system change become available through action. In systemic action research, there is an explicit presumption that action does not necessarily follow from analysis. Here, action can – and ought to – inform analysis which in turn can generate new action (Burns 2009).

Research is important because evidence is required; thus inquiries need to be documented so as to generate a sufficient and useable evidence base. Evidence enables the building of a case for action, testing of resonance within the system, and consideration of action options including the teasing out of unintended consequences.

The corollary concept, triple-loop learning, draws on a range of theoretical works and is used as a means to critically examine how a military organization "learns" and whether it is "learning" the things that most matter. This leads to three questions: "Is the organization doing things right? Is the organization doing the right things? How does the organization know what is right?" (Argyris and Schön 1996). It is a process that can be used to critically reflect on the military's ability to adapt to complex change and thereby fulfill its task of upholding national security.

Systemic action research, as a whole, has a number of key aspects. It is multistranded. This enables stakeholders and participants to consider issues from a range of different perspectives and so begin to understand the interconnections and influences between issues, for example, via co-learning and joint analysis. It involves multiple stakeholders and interest groups at different but related levels of hierarchy, for example, "on the ground" or in the immediate unit, within the wider local grouping or system, and in organizational or more strategic settings. This allows the range of key players to engage in "learning, dialogue and the co-construction of action; enhancing the chances that solutions will sustainable" (Burns 2009).

Of critical interest, systemic action research links informal inquiry and action with formal decision-making systems and networks of power. It gauges the significance of issues through the use of resonance rather than representativeness. This methodology is highly emergent in its design, thus seeking to mirror the emergence of the phenomena that it is exploring. Lastly, it requires the research convenors and participants to identify underlying patterns; surface and challenge underlying assumptions so as to identify systemic blockages; identify possible entry points, opportunity spaces, and leverage points to generate action and enter these "entry points" to discover where they lead; be bridges between different parts of the wider system; identify and catalyze powerful sources of leadership; and support action in multiple arenas (Burns 2009).

These distinctions and definitions are important because of the way different approaches can shape the problem definition, analysis, and subsequent solution options or recommendations. How a problem is viewed initially – and what the roots of the problem are – is often a judgment call. In this context, judgment is defined as a combination of experience, knowledge, and learning preferences (Bawden 1990).

Strategic Military Geography

Judgment is often required by military personnel, particularly in operations – be they war or non-conflict activities such as HADR. A key support to judgments and decision-making is military geography, which has long been part of defense doctrine and concepts because military activities are inherently geographic in nature (O'Brien 1991). "Military activities occur on landscapes with distinct physical and cultural character. Understanding how the spatial distribution of landscape elements affects the military operating environment at the tactical and operational scales, and how this applies to military concerns are the strategic scale, is the substance of military geography" (Harmon et al. 2004).

Military geography therefore provides an appropriate basis for a conceptual framework to enable analysis of climate change impacts, consider their implications for the military, decide on priorities, and take action. The term Strategic Military Geography (SMG) is derived from "military geography" and also draws upon the characterization of "global change" in the earth sciences, ecology and humanities, and "geopolitics" and "strategic geography" in the security and international relations disciplines. Using these different – and sometimes competing – constructs helps to encourage the multiple perspectives and cross-fertilization of ideas formalized in the systemic action research methodology.

There are four key tenets in the SMG Framework. The first is to think "big picture" and take a holistic or "helicopter" view, to look at the whole set of challenges and potential changes in the military operating environment in its broadest definition. This helps users to get a sense of the range of issues and how they interact and influence each other. The second tenet is to consider the relationships between the issues as well as understanding specific issues, that is, to take a systems view. The third tenet is to take a participatory approach and engage as broadly as possible – within the military, within the government, and within the science and research communities. The fourth tenet is to use a multilevel learning process that maps across tactical, operational, and strategic military domains. SMG employs these different principles concurrently and iteratively to provide a more comprehensive understanding and analysis, with which to generate options for situation adaptation or improvement.

The Multiplicity of Geographies

Traditionally, the two prime aspects of military geography are the physical terrain or landscape and the cultural characteristics or societal makeup of groups in the military operating area. In the SMG framework, the virtual world or cyber geography has been added as a distinct geography.

Thus, in this Framework, global changes in SMG can be analyzed as the nexus between biogeochemical changes in the Earth system (physical geography) and social, economic, and technical responses (cultural or human geography) and intangible technological considerations (virtual geography).

Physical geography encompasses the military geography domains of air, land, maritime, and more recently space (orbital and intra-solar). Physical geography also includes the diversity of the natural sciences and phenomena, such as sea straits, volcanoes, topography, weather, orbital space, terrain, vegetative cover, natural features, flora and fauna, wind and wave patterns, temperature, and rainfall.

Human or cultural geography is the human world and covers society, politics, philosophy, economics, science and technology, culture, and concepts such as the nation state, transnational corporations, international relations, the precautionary principle, and peacekeeping to name a random few. The focus here is on human activity systems, that is, particular and cumulative effects of human activities on groups of people and on their environment.

Human or cultural geography includes allied nations, neighbors, community values, local economies, recruitment, fallout from the global financial crisis, new technologies such as algae-derived biofuels, sustainable chemistry, gas-to-liquid conversion, nanotechnology, and gene therapy. It also encompasses attitudes and behaviors – individually and collectively, for example, toward physical environmental change, conventional power and energy generation, and future human development.

Socio-technical and economic responses fit within human geography and include domestic and international regulation, economic instruments, societal (nongovernment) reactions, and government activity as well as broader human activities, such as changing patterns of settlement, human demography, impacts of technology applications, and regional/global relationships including disasters and conflict.

Virtual geography (also known as cyber geography) is a recent addition to traditional military geography. It covers activities, phenomena, and effects in the virtual world. These include cyber terrain, simulation, satellite data, virtual reconnaissance, planning, and training as well as online gaming, communications such as e-mail and video link, social media, control networks for electricity grids and other applications, massive open online education courses, global research, and other types of collaboration via the Internet plus commerce, entertainment, and crime. More and more is happening in the virtual world, such that cyber security, hacking, and other types of activities designed to disrupt, disable, mislead, or financially disadvantage are becoming constant features of cyber space.

Interfaces and Interactions

All these worlds interact and influence each other, and all are affected by global change, including climate change. For example, the virtual world has physical aspects such as power sources, hardware and equipment, and development, trade, and disposal of hardware and software. Data collection and storage also have physical aspects. Hardware for the virtual world currently requires rare earths and precious metals, many of which occur in limited quantities globally.

The food-energy-water nexus is another example of the interactions between the three geographies. Production of food for human and livestock consumption depends upon water and energy and for much of it arable land as well, thus linking physical and cultural geography. Agricultural commodity and processed food production, trade, and distribution can be researched, modeled, and simulated virtually, thus linking physical and cultural geography to the virtual world. Production systems can be controlled electronically and growing conditions monitored and adjusted, for example, by restricting or releasing water, via the Internet, situating these in the virtual geography domain. Food production and consumption often have social rituals attached to them, as well as financial value and social status.

Competition for energy sources and energy efficiency also has effects in the physical, cultural, and virtual worlds. Physical geography, for example, yields locations of sources, production, distribution, and consumption. Cultural geography encompasses investment finance, pricing, and social attitudes to different types of energy and how much people or organizations are willing to pay. Virtual geography provides for aspects such as exploration imagery and analysis, planning and design of production facilities, calculations of cost-effective shipping routes and tonnages, data collection on things like consumption interests and intentions that can be used to inform extraction or production adjustments, and complex, real-time price calculations of end products.

Analysis of Global Changes in Strategic Military Geography

The implications, particularly for future operating conditions, mission profiles, and energy resilience, of global changes in SMG, including climate change, are of great significance to military organizations, especially for future preparedness and planning. As military forces with a range of responsibilities, as large employers, as key implementers of government policy, as consumers of goods and services, and as stewards of national technological and biophysical assets, military organizations need to be cognizant of the implications of these changes for organizational and capability decisions that need to be taken now that will have impacts over the coming decades.

Reducing greenhouse gases (mitigation) while implementing adaptation measures represents a fundamental two-track climate change risk management strategy. Military planners routinely operate under uncertainty and make decisions based on incomplete information. If a battlefield commander waited until all facts were known about an advancing enemy, they would put their troops at risk (O'Brien 1991). Addressing climate change impacts on defense and national security can be seen in the same way.

Climate Change Effects

Changing geography and climate will have a range of effects on military forces. These can be categorized in three ways to enable understanding, help generate responses, and aid in decision-making:

First-order or direct effects include changes in the physical operating domains of land, sea, air, and space. This covers effects such as changing wind and wave patterns, strength, speed, direction, more turbulent, and variable. Changes in ocean circulation, wind currents, and atmospheric composition will impact on the conduct of operations, the usability and livability of military bases and facilities, and access to civilian infrastructure.

The conduct of operations may be more challenging physically and psychologically for military personnel training and conducting missions in harsher operating conditions and in dealing with civilians in desperate circumstances. Harsher operating conditions and more frequent support to disaster relief will reduce the service life of many military platforms and much equipment and require more maintenance at shorter intervals. This will affect military budgets, planning and acquisition cycles, and training regimes as military hardware is replaced more often. Life cycles of military equipment, particularly major platforms such as ships, planes, and ground vehicles, may be shortened as a consequence of changed conditions, placing increased demand also on maintenance, life-cycle costs, capability replacement, and disposal regimes.

Without remediation, the usability and livability of military bases and facilities may also be degraded. Airfields, ranges, wharves, fuel, and chemical storage facilities, for example, may become subject to flooding and inundation, increase maintenance in hotter drier conditions, or require upgrade or early replacement due to changed building codes or other regulations. There are implications too for the military workforce in terms of work health and safety, which would likely have organizational impacts on duty of care obligations, workforce productivity, and injury compensation arrangements.

These physical effects, particularly more severe weather events, changing rainfall patterns, and increased temperatures, are already causing greater stress on human populations; their infrastructure and support systems including food, water, and other supplies; and their distribution and waste disposal. Primary health impacts for people, plants, and animals include greater heat stress, more injuries, and reduced productivity because of warmer weather, particularly during the night as this affects rest and refreshment.

Operations and training may also be affected by changed access to harbors due to altered wind and ocean currents. On the east coast of Australia, for example, this could be exacerbated by the loss of significant portions of the Great Barrier Reef.

Second-order or indirect effects include changing mission profiles particularly the likelihood of greater demand for military support to civil communities, humanitarian assistance, disaster relief, peacekeeping, and reconstruction activities. A sufficiently large increase in demand for such missions will have impacts on training regimes, mission planning, disposition of forces, acquisitions, strategic planning, and military-military and civil-military cooperation. For example, increased deployment of military forces for reconstruction efforts, certainly in the Australian context, could require greater recruitment and training of people with the required trades and skills.

Another second-order effect is the impact on tasking and range. For example, Antarctica is changing much more quickly than scientists expected. At the same time, international interest is steadily increasing in Antarctica's role in global climate change and in Antarctica's biological and other resources (ASPI 2013).

Changing patterns of diseases, disorders, and pests are already affecting people, commercially valuable and emblematic (or psychologically valuable) animal, and plant species. These include changes in the ranges of vector-borne diseases, increased allergies, and air pollution.

The risks to human health from climate change include: injuries and fatalities related to heat waves and other severe weather events; spread of some infectious diseases from rising temperatures and changes in rainfall; water and food contamination from rising temperatures, changes in rainfall patterns, and extreme events; exacerbated respiratory allergies from increased allergens (pollens and spores) in the air; exacerbated respiratory and heart diseases in response to increases in some air pollutants; mental health problems in those experiencing physical and economic impacts; and the health consequences of population dislocation as some regions become uninhabitable (McMichael and Butler 2009).

A further second-order effect relates to energy – access, reliability, and security of supply and storage, as well as increased cost volatility. Energy sustainment is a major issue for most, if not all, military forces and a key part of building organizational resilience. Military organizations tend to be significant users of liquid fuels and to have some specialized fuel requirements. Given the rising cost of fossil fuels and the declining energy-returned-on-energy-invested surrounding extraction and production of liquid hydrocarbon deposits, energy sustainability is likely to become a critical issue for military organizations. This is particularly so as many military assets, including most of the larger platforms such as ships, planes, and submarines, are optimized for fossil fuel use. An exacerbating factor is that many military assets have specialized requirements that cannot be met by the current suite of alternative fuels.

Thus, there are risks and vulnerabilities in current military energy acquisition and management. In particular, change in energy demand, plus gaps in energy management, research, and reporting, could lead to significant unfunded cost pressures and potential future restrictions on operational capability.

Third-order or distant effects include economic losses which can have flow-on effects to military funding, implications for the military's reputation, ability to recruit and retain staff, and changes in the broader workforce that will impact on the recruitment pool. Feedback loops are important to consider. In terms of individual and population health, tertiary (or systemic multiplier) effects include famine, increased likelihood of conflict, large-scale migration or species decline, and potentially economic collapse (Butler 2014).

More severe weather will not only create social and economic adversity, it will have knock-on effects in terms of greater insurance premiums and more stringent or changed requirements for buildings, energy efficiency, the use of renewable energy, further or new restrictions on access to and use of chemicals harmful to humans, biodiversity, or the climate. This could loop back to restrict access and operational capability of military forces to finance, facilities, and essential resources such as specific chemicals.

Another financial impost may be liability for carbon taxes or carbon emissions – both directly as an organization and indirectly through increased cost transfers from industry to military forces. This may manifest in higher initial costs, increased legal liabilities and higher maintenance, and disposal costs. For example, in 2012/2013 the carbon tax liability of the Australian military was around A$80 million, which was not included in budget estimates and as a consequence was unfunded (Thomas 2012).

Military Implications and Risks

Internal Australian military analysis and broader analysis of available literature reveal four broad risks for the Australian military. These are (1) increased international, regional, national, and human security risks, (2) degraded homeland infrastructure, (3) altered environmental operating conditions, and (4) business continuity risks.

Firstly, climate change is set to have major geostrategic implications that will affect global, regional, national, and human security. The 2014 US Quadrennial Defense Review (USDOD 2014) stated climate change "will devastate homes, land and infrastructure," exacerbate water scarcity, jeopardize food security, increase resource competition, and place stress on economics, societies, and governance institutions around the world. This Review reflected earlier US national security assessments by reiterating that climate change will act as a "threat multiplier," thereby "increasing the frequency, scale and complexity of future [Defense] missions." The IPCC Fifth Assessment Report (AR5 Working Group II 2014) also identified a number of geopolitical and human security risks due to climate change including new contestations over territory on land and sea, threats to territorial integrity, and the very viability of states.

The IPCC report also noted that "there is justifiable common concern that climate change . . . increases the risk of armed conflict in certain circumstances" and that "human security will be progressively threatened as the climate changes." Indeed, climate change is provoking an upsurge in the intensity and frequency of natural disasters including floods, wildfires, cyclones, droughts, and extreme weather events.

Data from the Centre for Research on the Epidemiology of Disasters (CRED) shows an unprecedented growth in natural disasters since 1900 and their attribution to climate-related events (Fig. 1) (CRED 2012). Total global natural disasters in 2011, for example, killed around 31,000 people, generated a further 245 million victims, and resulted in economic losses of US$366 billion (Guha-Sapir et al. 2012). Most of the damage caused by natural disasters consistently occurs

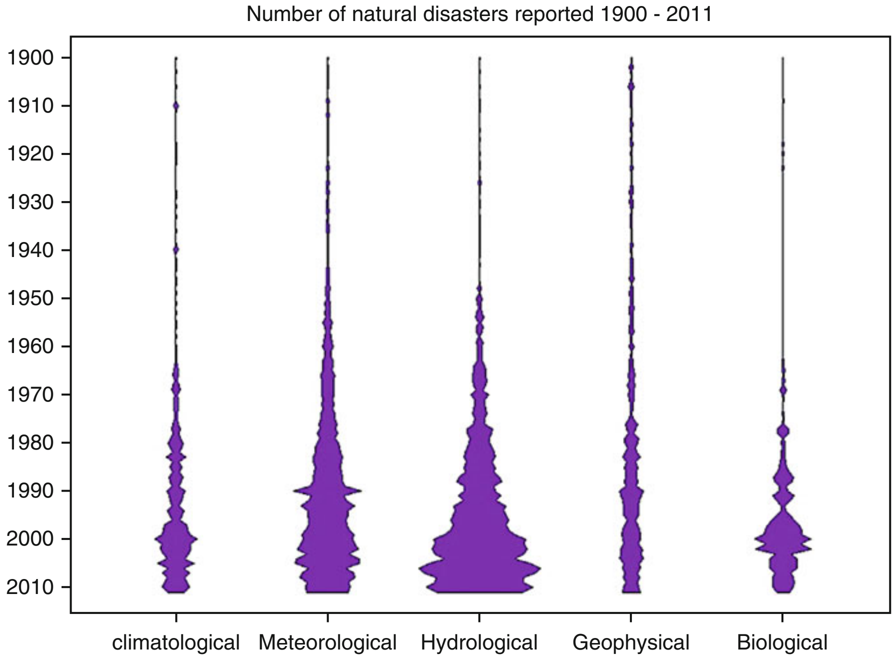

Fig. 1 Number of natural disasters reported by category 1900–2011. Note the increase in climate-related natural disasters (climatological, meteorological, and hydrological) (Source: CRED)

in the Asia-Pacific region. In the same year, Asia accounted for 44 % of global disasters which equated to 86 % of victims and 75 % of the damage (CRED 2012). Civilian authorities (at domestic and international levels) now regularly expect (and demand) military capabilities in order to cope with the increasing scale of natural disaster effects.

Even as a developed nation, Australian people are vulnerable to climate change. Major climate-related events in recent years have seen large-scale deployments of Australian military forces to restore services, repair infrastructure, administer aid and medical provisions, as well as conduct low-level security tasks. Recent Australian military support to the 2009 Victorian bushfires, Queensland floods, and Cyclone Yasi in 2011 saw substantial military contributions to response and recovery.

During the Operation Flood Assist in Queensland, some 1,500 military personnel were deployed to 58 townships across 21 municipalities from Townsville to Toowoomba (Department of Defence 2011). No longer is the summer break considered a "stand-down" period of rest and relaxation – rather it has become part of the Australian defense operational rhythm. In 2011 the Headquarters Joint Operations Command issued a standing order requiring particular defense force units to be ready at short notice over Australian summers in the event of a troika of natural disasters including floods, fires, and cyclones. Almost unwittingly, climate change is now influencing Australian military force generation.

The second implication of climate change on the ADF concerns the degradation of its homeland strategic infrastructure. Rising sea levels, as an example, are set to pose significant risks for a number of military bases located at or near sea level. The damage caused by a combination of sea-level rise, storm surge, and river flooding may, however, extend far beyond maritime infrastructure. Impacts could include degradation of military buildings via inundation, coastal erosion, or direct wave action; degradation of roads on military land via coastal erosion from inundation, restricting base access and capability or damaging road surfaces and foundations; degradation of airstrips via inundation, restricting base access or damaging runway, taxiway, and flight apron surfaces and foundations; and degradation of military pier and marine infrastructure via inundation or wave damage, restricting base access, safe use, or capability.

Other impacts include damage to environmental assets via inundation or wave damage leading to degradation of important flora and fauna habitat, changes to the nature of contaminated land or failure of storage facilities, and environmental pollution; degradation of heritage sites via inundation or wave damage leading to damage to built or cultural sites of significance; degradation of training areas and ranges leading to reduced preparedness; degradation of communications, explosive ordnance testing, logistics, and storage sites; and increased risk of large-scale fires on military training grounds due to lengthening fire seasons and reduced precipitation causing a "drying out" of critical areas.

The costs of relocation or adaptation measures for military bases are not insignificant. A proposed relocation of Fleet Base East from Sydney Harbour 200 km south to Jervis Bay in the 1980s was estimated at over A$2 billion (2011 prices) (Thomas 2012).

Arguably, such risks are already eventuating and being experienced by the Australian military. In October 2013, around 50,000 ha was burnt out and three homes destroyed during the State Mine fires which began during a military training activity at the Marangaroo training area. As noted by the Australian Climate Council in its 2014 report, the Angry Summer, the Australian fire season, is increasing in duration – starting earlier and ending later – with the added threat that "climate change is [now] driving an increase in the risk of bushfires" and is concomitantly "increasing the intensity and frequency of [such] extreme weather events."

The Australian military must adapt to this increased risk, for example, by enforcing stricter risk assessments during training activities. Likewise, the military will need to enhance the resilience of its infrastructure to withstand extreme fire events and perhaps to develop the capability to respond to such events in case civilian fire services are overwhelmed. This latter point raises an important facet of how climate change will have second-order impacts on the Australian military by degrading broader national infrastructure that is crucial to supporting operations and business continuity (Thomas 2014).

A 2011 report Climate Change Risks to Coastal Buildings and Infrastructure (Department of Climate Change and Energy Efficiency 2011) concluded that A $226 billion in commercial, industrial, road, rail, and residential assets are potentially exposed to sea-level rise. Included in this assessment were many facilities and services that support defense activities including 258 police, fire, and ambulance stations, five power stations, 75 hospitals and health services, 41 landfill sites, three water treatment plants, and 11 emergency services facilities. Suffice to say, climate change has second-order impacts on Australian infrastructure that if degraded might significantly disable elements of the Australian military or, as a minimum, its ability to respond to either warlike or natural disaster situations.

The third area of impact on the Australian military is that climate change will alter the fundamental environmental conditions in which the military will raise, train, sustain, and operate. Examples include rising sea levels; increasing ocean acidification; increasing ocean and atmospheric temperatures; changes to rainfall patterns; increasing intensification of extreme weather events; increasing rates of glacial, polar, and permafrost melting; and broader spread of disease.

Arguably, the greatest long-term risk (30–50 years) is the risk of sea-level rise. More immediate, however, is the increased risk of extreme weather and hotter temperatures. Increases in temperature, for example, may change how forces train, particularly as extreme temperatures become the norm rather than the exception. Australia's lead scientific research organization the CSIRO, for example, predicts that under the IPCC business-as-usual scenario, Darwin (home to a significant proportion of Australia's military ground forces and visiting military forces) will experience more than three times the number of extreme temperature days (above 35 °C) by 2030 (Cleugh et al. 2013).

Increases in ocean acidification may also lead to maritime vessels requiring more frequent maintenance regimes. Changes to ocean buoyancy due to lower densities from ice melt may affect submarine operations. Extreme weather events are also likely to see a larger portion of the Australian military's operational duties committed to humanitarian assistance and disaster relief.

Finally, there is the impact that climate change will have on business continuity. This is a broad-ranging concept that includes regulatory impacts, research and development opportunities, personnel, and recruitment.

Military Responses

From this suite of risks, three response or action areas were identified. These are (1) preparing for changes in mission profiles or military tasking; (2) adapting to changes in operating conditions, risks, and costs; and (3) building infrastructure resilience and energy sustainability.

Changes in Mission Profiles

Changes in military tasking are likely in the next 10–30 years as climate and other global change impacts intensify and interact. Military organizations often play a central role in risk mitigation and as responders in the case of natural disasters, pandemics, and humanitarian catastrophes. Militaries also often play central roles in reconstruction activities and may, in extremis, be required to help restore law and order and contribute to stabilization and resource protection activities in the case of national, regional, or global crises.

There is an expectation – and emerging evidence – of greater demand for humanitarian assistance and disaster relief (Campbell 2013). Militaries are also likely to experience greater deployment to peacekeeping missions, support to the civil community, border protection, and support to civil authorities in emergencies.

New roles for the military could well include providing support to research, trials, and deployment of geo-engineering activities as well as protection to civilian geo-engineering actions. Military interdiction of unauthorized geo-engineering activities is equally, if not more, likely. Given military observation capabilities, an even more likely role for military forces will be monitoring geo-engineering research and trials and environmental conditions to ensure that any geo-engineering activities are detected and the impacts recorded for military and civilian analysis. Such monitoring would need to be done in cooperation with other government agencies, research communities, and international organizations.

Military organizations could also be tasked to monitor potential geo-weaponeering developments, including technologies, tactics, trials and simulations, strategy, and planning. A New Zealand Defence Force study also pointed to new or intensified activities such as persistent border surveillance against illegal resource extraction, for example, fishing or mass people movement. This could be done nationally, for and with neighboring countries without the necessary assets, or in a regional partnership (Boxall 2012).

Given that the polar regions are changing far more quickly than scientists expected and much faster than many other regions (IPCC AR5 WGI 2013), there is increasing activity and interest in both the Arctic and the Antarctic, for shipping, biological and other resource extraction, surveying, and research. Parts of Tasmania, New Zealand, the Antarctic, and Southern Ocean provide near-ideal conditions for climate remediation activities such as stratospheric sulfate seeding and ocean iron seeding (Karoly 2012). Construction of research centers in the Antarctic, resource surveying, mapping, and other research are expanding with many countries using their military assets to undertake these operations (ASPI 2013).

More countries are joining the Antarctic Treaty as well. While there is currently a moratorium on the exploration and exploitation of Antarctic mineral resources (the Madrid Protocol 1991), this expires in 2041. In any case, it is currently uneconomic to extract land or seabed-based minerals. This may, however, change in the coming decades if the globe continues to warm and the human world becomes more resource hungry (ASPI 2013). Antarctic Treaty member countries therefore may increasingly deploy military assets to support their strategic, research, and economic interests in the southern polar region.

Similarly, as the Arctic Circle continues to lose ice mass and with projections of a summer ice-free Arctic before 2050 and very likely earlier (Overland and Wang 2013), countries with interests in the Arctic are tasking their militaries with exercises, research, and exploration in the northern polar region. Tensions are surfacing over shipping routes and rights of passage through specific waterways that some countries argue are sovereign and others view as international shipping lanes. There are also increasing interest and activity in Arctic hydrocarbon fields, exacerbating tensions between Arctic Council member countries (Masters 2013).

Expansions in space-based surveillance, communications, and in the future possibly energy generation, industrial manufacturing, and climate remediation are also likely to provide new tasking for military organizations. These kinds of activities are likely to mean military organizations will need to cooperate more and more closely with other government agencies and commercial entities.

Changes in Operating Conditions, Risks, and Costs

This likely increased demand for military operations other than war, including HADR, comes at a time when many governments are reducing spending on military forces (Perlo-Freeman and Solmirano 2014). Increasingly constrained defense budgets means that many military forces will need to rethink how they conduct military operations and how they maintain military capabilities, both human and technological.

Changes in operating conditions, such as severe weather and changing patterns of diseases, are likely to pose greater risks and increase the costs for military forces in terms of damage to infrastructure, bases, and equipment and harm to personnel and their families.

Infrastructure Resilience and Energy Sustainability

Reducing demand, increasing efficiency of energy use, hardening infrastructure, and increasing energy self-sufficiency through the use of alternatives and renewables can enhance national security and military operational effectiveness. It thus makes sense environmentally, operationally, and financially, though there are challenges. Alternatives include synthetic fuels, gas to liquid and coal to liquid and renewable energy derived from solar, wind, biomass, and geothermal energy, waste to energy, hydrokinetic and ocean energy, and fuel cells.

Another way to increase energy sustainability is to take an integrated systems approach, one that encompasses activities and issues across the military rather than leaving energy issues to each service or part of the organization. This could reduce cost pressures by lowering energy demand, enhancing supply chain reliability, and increasing energy efficiency. Military energy requirements, both physical and strategic, could also be situated within broader government and industry energy contexts, enabling systems-level linkages to broader policies and also other military energy strategies. Australian, the US, the UK, and many NATO militaries, for example, have developed or are developing comprehensive energy frameworks or strategies to maximize operational energy effectiveness and minimize demand and energy costs across the board.

Assuming this is the "critical decade" (i.e., that decisions made between now and 2020 will determine the severity of climate change over the next 50–100 years), military forces – like other organizations – need to start making some hard decisions that balance current costs against future well-being. Taking such an approach will also have consequences for future military planning and acquisitions, particularly if it is accepted that the range of technologies available now are the tools to be used for adapting to, and mitigating, climate change.

General Military Capacity to Engage in Climate Adaptation

Militaries generally have much of the capability and competence required to address climate change impacts but can benefit from more collaboration internally and by reaching out to expertise and experience elsewhere – such as gaining insights from other militaries, government agencies, scientists, and other subject matter experts.

There are three broad categories of military capacity that could, in combination, be applied to climate adaptation: institutional, organizational, and individual.

In an institutional sense, governments and military leaders can reorientate military forces and expand their *raison d'être* to include addressing climate change – directly and indirectly – directly via explicit inclusion in military strategic objectives of concepts such as collective environmental security, defense of national critical resources, and carbon-neutral operations and indirectly through a greater focus on military operations other than war, especially resilience building, HADR, and aid to civil authorities. This could be promulgated through strategic planning, implementation of operational guidance, joint exercises, war gaming and simulation, future capability planning, and acquisitions.

Organizationally, military forces can consider how missions are achieved including mobilization, deployment, sustainment, and recovery/return. Focus issues include: How are power and energy thought about and managed? Are there carbon and cost savings to be had by changing practices and attitudes toward liquid fuels and fixed power?

Understanding adaptation approaches, particularly methods for analyzing the likely impacts on military capability, personnel, and budget, can be incorporated into organizational structures and processes, for example, by requiring that military groups and agencies take climate change issues into account in planning and other activities. Military research can also inform other national and local decision-making process. Adaptation responses for military bases often have impacts for local infrastructure such as changed drainage patterns and do not present cost-effective options in isolation requiring planning to be conducted collaboratively.

Another organizational response is the appointment of a high-ranking military officer to be an advocate and focal point for climate change and related issues, including coordination of effort across the military and between the military, government, and broader society. This may require a small, dedicated specialist team to coordinate analyses of change impacts, military operational and estate vulnerability assessments, and strategic response planning across the organization.

Military organizations can also support action at the individual level of defense personnel and their families. Militaries can be viewed as human activity systems, wherein the individuals in the system have some influence over the behavior of the system as a whole. This military system interacts with other systems – or, in this context, communities. The individuals within the military system can choose to change their personal habits and, by demonstration or advocacy, encourage change in others, for example, by taking "green days" and/or by cycling, walking, car-pooling, or taking public transport to work whenever possible. Low-carbon commuting can be encouraged by individuals or units setting up a "green miles" club or competition.

Governments and military organizations can, for example, support cycling schemes through tax rebates, subsidized prices, or providing a pool of bicycles as well as infrastructure such as bike lockers, shower and change facilities, and bicycle paths or lanes on roads and tracks. Support for public transport can include provision of tickets or transport and lobbying governments to provide public transport and bus stops. Car-pooling can be encouraged through privileged parking and reductions in parking fees.

Best Practices

Military organizations are developing best practice approaches to deal with climate change adaptation. These include adopting strategy development principles that support a coherent approach to climate change adaptation.

To achieve best practice adaptation, current military experience shows that there is a need to develop a coherent climate change adaption strategy that is phased by decade and synchronized with capability acquisition; it is necessary to collaborate more internally to enable a coherent and coordinated whole-of-organization approach to climate change adaptation and to increase energy efficiency, reduce demand, and consider alternatives to fossil fuels wherever possible.

This includes the use of reusable rather than disposable equipment, for example, utensils and water bottles; developing public private partnerships, for example, the Carnegie wave energy trial at HMAS Stirling Naval Base in Western Australia; and renewable energy, for example, powering forward bases via energy from waste. These kinds of activities will have the added benefit of reducing the bulk and cost of supply chains and protective details for liquid fuel convoys.

Larger militaries with alliances requiring interoperability can use this need to encourage and support allied militaries to use blended fuels or other lower-carbon alternatives. Militaries of medium to large size can contribute to adaptation by building future resilience into reconstruction, peacekeeping, and disaster relief efforts.

Likewise, military forces can use exercises to practice HADR, cooperate with nongovernment organizations and other government agencies, and enhance the skills and reputation of military forces by delivering aid and support to communities. For example, New Zealand has undertaken a very successful series of exercises, called Operation Twilight, in the South West Pacific along these lines (Boxall 2012).

Further research and investigation by military forces will help to determine, quantify, and cost impacts on them and enable the development of strategies and actions to adapt better to climate change and support their countries to do so as well. Some issues that ought to be considered are:

More research could be conducted on the impacts on service life of hardware and impacts of atmospheric and marine environment changes on observation and communication technologies, optimizing effectiveness and minimizing energy expenditure through a balance of live exercises, training, and simulation. In the same vein, research could be conducted on changing technical specifications, for example, for military-specific fuels, to accommodate new power and energy technologies and alternative fuels. This would include certification of new fuels, oils, and lubricants.

Military organizations could, on their own or in collaboration with commercial providers, conduct trials of alternative energy generation such as wave power and biogas from waste. This would include ensuring that any alternatives meet military specifications for current and future assets. Another key area is energy efficiency research, for example, into reducing surface ship fuel use through design changes and bio-repellent hull coatings and changing the energy generation mix on board to ensure least use and highest benefit from fossil fuels and other high-polluting inputs.

Military assets, such as hydrographic research and mapping facilities, could be used to contribute to data collection and understanding of oceanic and other climate change impacts. These are suggested contributions and support that military forces can make to climate change adaptation and are not meant to be definitive. There would be many other ways in which military forces can demonstrate best practice and support to climate change adaptation.

Conclusion

As demonstrated in this chapter, climate change adaptation is a significant issue for military organizations. They are regularly involved as responders to natural disasters and often play a central role in reconstruction. Climate change impacts on the military include potential changes in mission profiles, increased costs, more humanitarian and disaster relief operations, and changes to their power and energy arrangements for cost, carbon reduction, and operational reasons.

Many military organizations will be pivotal in climate adaptation and response. One way to contextualize climate change impacts into military organizations is via the construct of Strategic Military Geography (SMG). This is a three-dimensional decision framework, underpinned by the systemic action research methodology which integrates systems thinking, participatory action research, and triple-loop learning.

Military issues, especially those with global drivers and connections to other issues – such as climate change and energy – can be teased out through the SMG framework, enabling identification of key implications and how they relate to each other as well as impact on military operations and organizations. This provides a richer picture of issues and their context, which in turn means that organizational impact analysis will be more comprehensive and decision-making can be more keenly focused with better results and fewer unintended consequences now and in the future.

Thus the SMG Framework supports system-wide long-term planning, fosters greater dialogue between critical stakeholders, and enables transfer of learning between militaries and other organizations.

Roles for military organizations in climate change adaptation include building resilience within themselves and their communities, hardening infrastructure to ensure continued operations when required, and providing technological and other leadership in seeking out or developing cost-effective adaptation measures.

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Streamlining Climate Risk and Adaptation in Capital Project Development

Lisa Constable and Ioannis Chrysostomidis

Contents

Abstract

Climate change is already presenting material risks and opportunities to business and industrial sectors. As extreme weather events appear to become more frequent with climate change, these risks and opportunities have grown in prominence and, for a growing number of companies, have become closely aligned with project performance.

Understanding and managing climate risk and adaptation, at a project level, will be central to ensuring business continuity and reducing costs. Key to enhancing the resilience of future economic stability and growth is to ensure that new

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project developments consider climate risk and incorporate adaptation measures in their design. This is particularly important in relation to utilities, infrastructure, and the extractives sector (i.e., mining and oil and gas activities). Furthermore, building resilience to climate change and incorporating adaptation measures into project design, as well as impact management programs – such as Environmental and Social Impact Assessments (ESIAs) –, is now being mandated by a growing number of financial institutions, as well as national and state governments.

Climate change also presents a new dimension to the traditional impact assessment conceptual framework in that it implies a dynamic rather than static baseline from which project impacts occur. This means that climate change, occurring irrespective of the project, may have the effect of altering the overall significance or magnitude of project impacts on the human and natural environment.

This chapter outlines these requirements at a high level and discusses integration of climate risk and adaptation into the capital project development life cycle through compliance with lender requirements, Environmental and Social Impact Assessment procedures, and internal risk management processes. It also presents a simple step-by-step approach to streamlining assessment within the project development process.

Keywords

International finance institutions • IFI • Environmental and social impact assessment • ESIA • Climate change • Business risk • Adaptation • Risk management

Introduction

Climate change is already presenting material risks and opportunities to business and industrial sectors. As extreme weather events appear to become more frequent with climate change, these risks and opportunities have grown in prominence and, for a growing number of companies, have become closely aligned with project performance.

Understanding and managing climate risk and adaptation, at a facility or project level, is central to ensuring business continuity and reducing costs. Key to enhancing the resilience of future economic stability and growth is to ensure that new project developments consider climate risk and incorporate adaptation measures in their design. This is particularly important in relation to utilities, infrastructure, and the extractives sector (i.e., mining and oil and gas activities).

Climate resilience and mitigation actions should be firmly on the agenda, particularly for major new infrastructure that can benefit from climate risk, impact, mitigation, and adaptation insights throughout its lifetime.

Furthermore, building resilience to climate change and incorporating adaptation measures into project design, as well as impact management programs – such as Environmental and Social Impact Assessments (ESIAs) – is now being mandated by a growing number of financial institutions, as well as national and state governments. At the forefront of this effort is the International Finance Corporation (IFC) of the

World Bank Group, which revised its *Performance Standards on Environmental and Social Sustainability* in January 2012. The Performance Standards (PS) now recommend the consideration of "relevant risks associated with a changing climate and the adaptation opportunities" associated with these risks (IFC PS1 2012) and identify the need to consider the impact of climate change on community risk and vulnerability as well as on ecosystem services and natural habitats, especially where they play a role in mitigating climate risk. These revised standards have since also been formally adopted by the Equator Principles Association, which provides a risk management framework for financial institutions in relation to determining, assessing, and managing environmental and social risk.

In addition to legislative and lender requirements, companies have internal processes aimed at managing risk through the project development cycle. Engineers routinely factor weather-related meteorological information into project design (e.g., operating envelopes, production schedules), but the extent to which this includes possible variations due to climate change is typically limited.

There are a number of complementary reasons why organizations undertake structured analysis of climate change impacts and adaptation within their capital project development proposals. A climate change risk and adaptation study can:

- **Ensure identification and management of all project impacts, in light of changing baseline vulnerability of the receiving environment**: Climate change not only poses risks to project infrastructure and operations but may also alter the sensitivity profile of both human and natural receptors to project impacts, resulting in potential increased significance and magnitude rankings for some impacts. If these issues are not explicitly evaluated, the project may result in unmitigated and unmanaged impacts to surrounding communities and natural environment, with potential regulatory, operational, and reputational implications for the project developer.
- **Help identify key vulnerabilities of the project to climate impacts and provide opportunities for adaptation/risk mitigation through design/operational measures:** Analysis and review of risks in the early design stages of a project will provide scope to identify risk mitigation (adaptation) actions that are integral to the project rather than "bolt-on," thus potentially reducing both the costs of belated remediation and the probability of costly impacts due to lack of project design resilience.
- **Demonstrate compliance with lender/donor requirements:** As mentioned above, international financing institutions are increasingly extending the scope of their requirements with respect to climate resilience and greenhouse gas mitigation.
- **Demonstrate compliance with emerging national regulatory requirements:** Some national and state governments are starting to formally require that the effects of climate change be considered in project ESIAs and associated studies submitted for regulatory approval. For example, governments in Australia, Canada, and the Netherlands are beginning to implement legal frameworks for incorporation of climate change within the ESIA process (Agrawala et al. 2010).

- **Identify the developer as forward-looking and responsible:** Well-designed and de-risked development solutions make good business sense over the lifetime of the project and create a positive reputation for those responsible.

This chapter outlines these requirements at a high level and discusses integration of climate risk and adaptation into the capital project development life cycle through compliance with lender requirements, Environmental and Social Impact Assessment procedures, and internal risk management processes. It also presents a high-level approach to streamlining assessment within the project development process.

Climate Risk and Adaptation in Project Finance Requirements

International Finance Corporation Performance Standards

The IFC, a member of the World Bank Group, provides financial services and investment in support of development in developing countries. Since many developing countries do not have stringent environmental and social legislation, the IFC has developed policies and standards against which investments are assessed to ensure that projects effectively address environmental and social issues.

The IFC adopted a sustainability framework in 2006 which sets out its strategic commitment to sustainable development and risk management. This was subsequently reviewed and the latest revised version came into effect in January 2012 (IFC 2012).

Included in this framework are eight performance standards (PS) against which a number of environmental and social sustainability risks and impacts of IFC funded projects are assessed. Recognizing the changing global risk landscape associated with climate change, the revised performance standards explicitly include the requirement to consider "relevant risks associated with a changing climate and the adaptation opportunities" associated with these risks (IFC 2012) and identify the need to consider the impact of climate change on community risk and vulnerability as well as on ecosystem services and natural habitats, especially where they play a role in mitigating climate risk.

The specific climate change-related requirements are summarized in Box 1. Note that since PS 3 relates exclusively to mitigating greenhouse gas emissions, the conditions have not been considered further in this chapter.

PS 1 is an overarching standard which mandates the need to consider climate risk within the project development process. The accompanying guidance note emphasizes that "a project's vulnerability to climate change and its potential to increase the vulnerability of ecosystems and communities to climate change should dictate the extent of climate change considerations in the risks and impacts identification process" (IFC 2012). Proportional to that vulnerability profile, the project should "(i) identify potential direct and indirect climate-related adverse effects that may affect the project during its life-cycle, (ii) identify potential direct and indirect climate-related adverse effects that may be exacerbated by the project, and (iii) define monitoring programs and mitigation and adaptation measures, as appropriate" (IFC 2012).

Box 1 (IFC) PS Climate Change Requirements

IFC PS 1

The risks and impact identification process will consider the emissions of greenhouse gases, the relevant risks associated with a changing climate and the adaptation opportunities, and potential trans-boundary effects, such as pollution of air or use or pollution of international waterways (IFC 2012).

IFC PS 3 Requires

- Measures for improving efficiency in consumption of energy, water, as well as other resources and material inputs
- Options to reduce project-related greenhouse gas emissions during the design and operation of the project
- For projects > 25,000tCO_2e/year quantification of direct greenhouse gas emissions within the physical project boundary and indirect emissions associated with off-site production of energy (i.e., purchased electricity)

IFC PS 4 Requires

- Projects must take into account the fact that communities that are already subjected to impacts from climate change may also experience an acceleration and/or intensification of impacts from project activities, since climate change effects may exacerbate their vulnerability.
- Projects must identify and mitigate risks and potential impacts on priority ecosystem services that may be exacerbated by climate change.

IFC PS 6 Requires

Determination of critical habitat should consider sites of demonstrated importance to climate change adaptation for either species or ecosystems.

PS 4 recognizes that project activities, equipment, and infrastructure can increase community exposure to health and safety risks and impacts, particularly for vulnerable groups, and requires that "communities that are already subjected to impacts from climate change may also experience an acceleration and/or intensification of impacts due to project activities" (IFC 2012). The standard further requires identification of "risks and potential impacts on priority ecosystem services that may be exacerbated by climate change" (IFC 2012).

The guidance notes accompanying PS 6 on Biodiversity Conservation and Sustainable Management of Living Natural Resources note that determination of areas of critical habitat should consider "ecosystems of known special significance to endangered or critically endangered species for climate adaptation purposes" (IFC 2012) as well as "sites of demonstrated importance to climate change adaptation for either species or ecosystems" (IFC 2012). Selection of mitigation measures should furthermore take into consideration "existing non-project related threats to biodiversity values," which include, among other threats, climate change (Farell et al. 2013).

Equator Principles

The Equator Principles (EP) represent the best available risk management framework for commercial financing institutions in relation to determining, assessing, and managing environmental and social risk. At the time of writing, 78 financial institutions in 35 countries have signed up to the EP, covering over 70 % of international project finance debt in emerging markets (EP 2013).

Member institutions commit to implementing the principles within their project financing policies and procedures on environmental and social issues. They will not provide project finance or corporate loans (on arrangements exceeding US$10 million) to organizations which are unable to comply with the EP (EP 2013).

For projects in "non-designated countries," i.e., those judged not to have sufficiently robust national environmental impact legislation, the assessment process must be in compliance with the IFC performance standards and environmental, health, and safety guidelines. Of the 31 designated countries, 21 are members of the European Union and the others are all industrialized countries.

The third version of the EP published in June 2013 lists "viability of Project operations in view of reasonably foreseeable changing weather patterns/climatic conditions, together with adaptation opportunities" as a potential issue to be addressed in the ESIA (EP III 2013).

Many of the environmental elements of the PS and EP are considered during the ESIA process and an example of how this is achieved is provided in the section below.

Climate Risk and Adaptation in Environmental and Social Impact Assessments

The International Association for Impact Assessment (IAIA) defines an Environmental [and Social] Impact Assessment as: "The process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made" (IAIA 1999).

The objectives of ESIA are:

- To ensure that environmental considerations are explicitly addressed and incorporated into the development decision making process;
- To anticipate and avoid, minimize or offset the adverse significant biophysical, social and other relevant effects of development proposals;
- To protect the productivity and capacity of natural systems and the ecological processes which maintain their functions; and
- To promote development that is sustainable and optimizes resource use and management opportunities. (IAIA 1999)

Level 1 – Intention	Level 2 – Guidance	Level 3 – Implementaion
Developed Countries Canada Spain European Union **Developing Countries** Bangladesh Dominica Kiribati Saint Lucia Samoa Solomon Islands Caribbean Community **Multilateral Organisations** Asian Development Bank Inter-American Development Bank World Bank	**Developed Countries** Australia Canada Netherlands **Developing Countries** Grenada Kiribati Trinidad and Tobago Caribbean Community	**Developed Countries** Australia Canada Netherlands

Fig. 1 The evolution of integrating climate change adaptation within ESIA (Agrawala et al. 2010)

Since most major capital project developments are required to undertake an ESIA, it makes sense to integrate climate change within this assessment. A 2010 study by the OECD indicates that a number of countries and multilateral organizations had begun working on incorporating climate change within the framework of environmental or Environmental and Social Impact Assessments (EIA/ESIAs) (Agrawala et al. 2010). Interestingly, more developing than developed countries had begun exploring options and developing guidance – predominantly small island developing nations and countries in the Caribbean (see Fig. 1). This is likely to be due to the significant projected impact of climate change on these nations in the future.

In the years since this study, the IFC has produced guidelines as discussed above and the European Union has issued detailed guidance (although not binding) on integrating climate change and biodiversity into EIA pursuant to the 2011 EIA Directive 2011/92/EU (EU 2013).

There are a number of entry points for incorporating climate change in the strategic phase preceding the initiation of the EIA/ESIA to the scoping, detailed assessment, and implementation stages. Figure 2 outlines how a climate risk and adaptation assessment could be included in the ESIA assessment process and asks key questions which can help focus the work.

An example of consideration of climate change during the ESIA process is the case of a proposed mine in the Northern Cape province of South Africa (confidential project). The area is hot and arid with rainfall occurring in infrequent intense thunderstorms. Climate change is likely to lead to hotter weather and less rainfall, exacerbating problems in an already water-stressed area. Specialists conducting studies during the ESIA process were provided with climate change projections in order to include changes in baseline meteorological data in their modeling to understand the impacts on surface water flow and groundwater recharge. This information allowed the design engineers to ensure the site selection and location of key

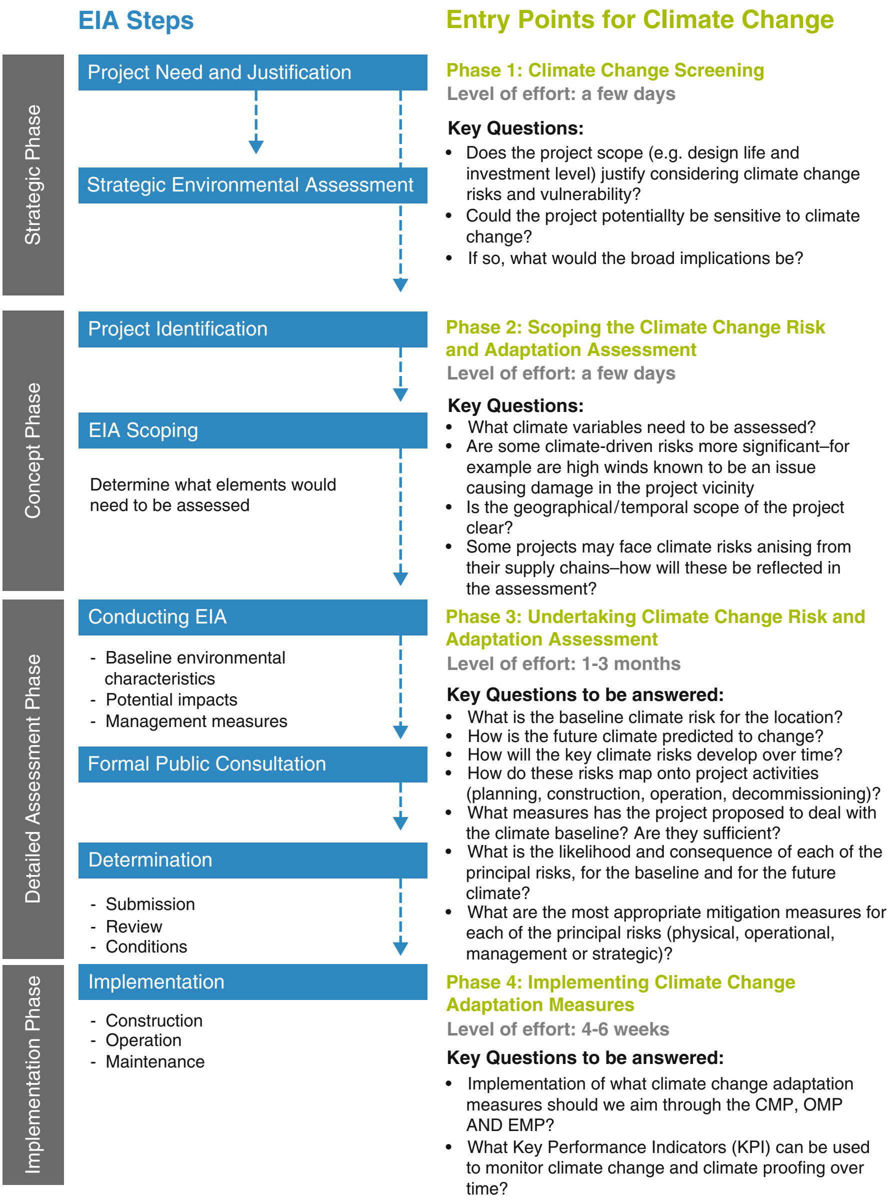

Fig. 2 Entry points for climate change risk and adaptation within the ESIA process (Adapted from Agrawala et al. (2010))

infrastructure was designed to withstand the magnitude of future events rather than only those experienced in the past. The potential impact of reduced water availability on local communities and agricultural activities was also investigated to ensure that the mitigation measures (climate change adaptation measures) identified during the

ESIA process would be relevant in the long term with a changing climate and could help ensure the sustainability of the project and surrounding community.

Integrated Climate Risk Management

Most, if not all, companies have some sort of risk management procedure which allows them to identify, analyze, evaluate, and treat business risks which arise during project development or operation.

The International Standards Organization (ISO) has developed a standard for integrating risk management practices within organizations (ISO 2009). The aim is to provide principles and generic guidelines on risk management to apply the procedures to existing management systems rather than to replace them. The standard provides a framework for integrated risk management and advice for risk identification, analysis, evaluation, and treatment.

Consideration of climate risks within a standard risk management approach can sometimes go a long way to managing the impact of climate change on the organization in a manner which does not require new systems or approaches.

Figure 3 illustrates how assessment of climate change risk and adaptation could be embedded within the integrated risk management framework outlined in ISO 31000. This process is explained in more detail below.

Many organizations will already be managing risks from extreme weather events and assessment of how climate change might amplify these risks simply requires addition of the increase/decrease expected in the future based on climate change projections.

Quantitative assessments focus on assessing risks that arise from an increasing frequency and severity of extreme weather events using likelihood/consequence based on traditional risk management approaches. Baseline or existing risks are assessed according to the method outlined in Fig. 4.

Once the baseline risk has been identified, frequency and severity parameters can be modified based on values that come from climate change projections as illustrated in Fig. 5.

The approach outlined above has been piloted through the development of guidance for integrating analysis of weather and climate risk into the operational risk management procedures of a global mining house (confidential project). By utilizing existing processes, the burden of additional processes/requirements is reduced and the effectiveness of risk management enhanced through ensuring that the amplification of existing risks as a result of climate change is effectively captured in the risk register. For example, fatigue management plans consider the impact of higher temperatures on staff working outside; slope management plans consider the risk of erosion/landslides from more intense rainfall in the future. The result is that the amplification of risks as a result of climate change is automatically considered within the day-to-day management of risks and controls and the likelihood of unanticipated events causing damage or business interruption is reduced.

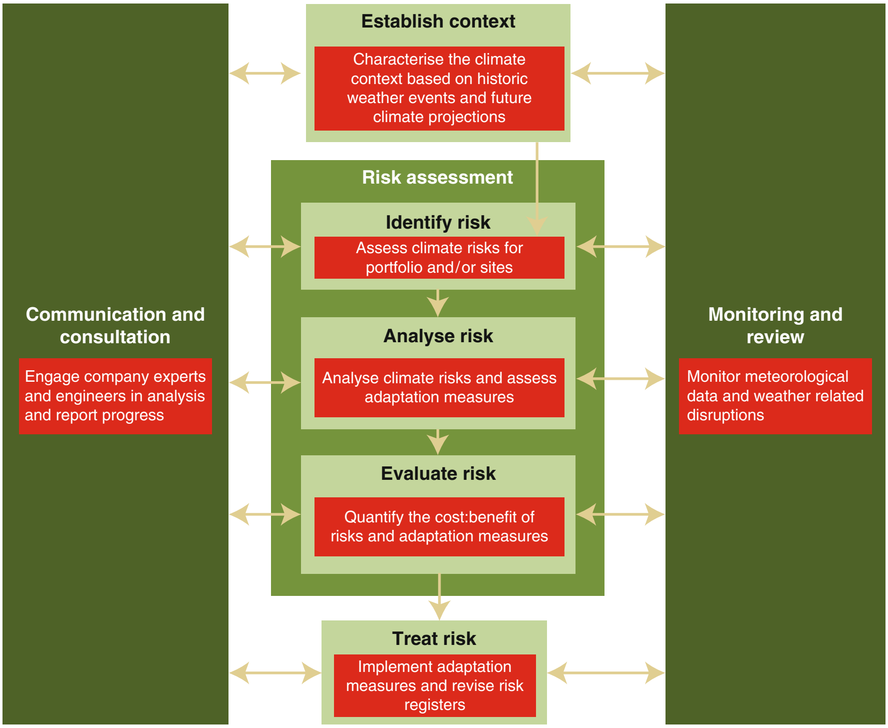

Fig. 3 Embedding climate change assessment within the integrated risk management framework

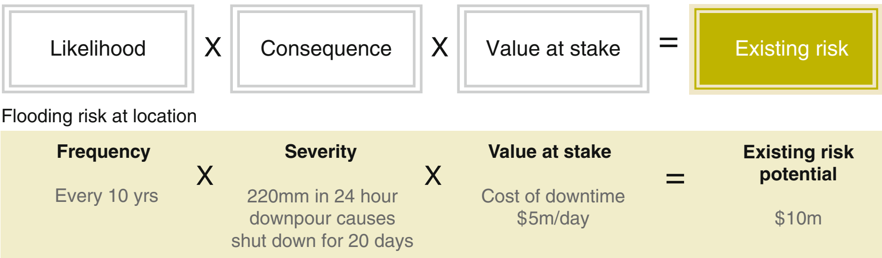

Fig. 4 Assessing baseline risk (Chrysostomidis and Constable 2014)

Streamlining Climate Risk and Adaptation in the Project Development Process

Businesses already have numerous risk management and impact assessment procedures in place, and incorporation of climate change assessment within these processes could help enhance resilience in a more efficient and effective manner than implementing stand-alone procedures in parallel.

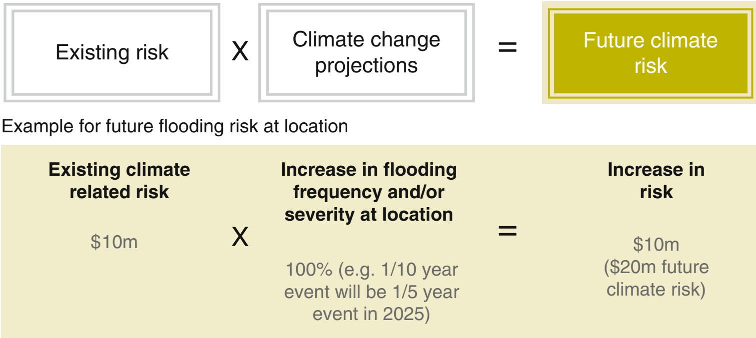

Fig. 5 Estimating future risk (Chrysostomidis and Constable 2014)

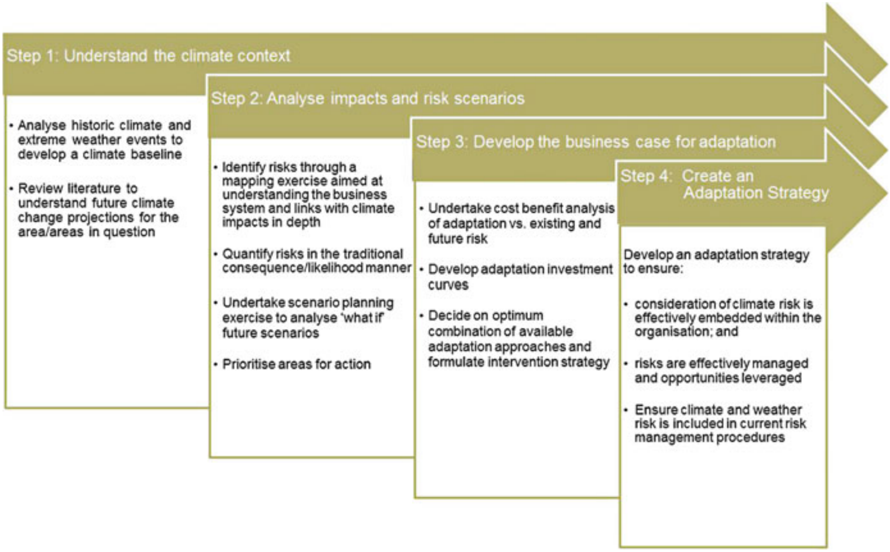

Fig. 6 Overview of climate risk and adaptation assessment process (Chrysostomidis and Constable 2014)

Figure 6 illustrates a simple four-step approach to understanding and managing the risks associated with extreme weather and climate change in a business context. The approach is discussed in detail by Chrysostomidis and Constable (2014) and provides a good starting point, in conjunction with the IFC Performance Standards and associated guidance, for the analysis required to ensure that climate risk is appropriately considered during the capital project development process.

The remainder of this section provides advice on how climate change can be incorporated in the capital project development life cycle through incorporation in ESIA as well as internal project team activities.

Project Team Analysis of Climate Risk and Adaptation in the Project Development Cycle

The approach to assessing climate risks differs depending on the stage of project development. While climate risk and adaptation can be addressed to a certain extent through the ESIA process, it is important that it is also incorporated in the business project approval process (i.e., each decision stage gate in the project development and evaluation process) in order that the risks and opportunities are fully considered through the decision-making stage gates throughout the project life cycle. It is recommended that a designated person act as liaison between the ESIA team and project team to ensure that the necessary information is gathered and incorporated effectively with the project development and evaluation process. This role will be particularly important where climate risks are expected to be the greatest. Figure 7 provides an overview of activities associated with climate risk and adaptation through the project development life cycle, and these are discussed in further detail in the remainder of this section.

Concession, Acquisition

Climate risk should be considered at a high level during due diligence prior to acquisition of a site or concession area. If a company is investigating a range of options in different geographical locations, it may be that the risks from weather at one site, e.g., in an area which is regularly subjected to hurricanes and flooding, outweigh the benefits and that the site (with similar reserves and potential economic return) in a more temperate climate would be preferred.

Exploration

During exploration, the main purpose of considering climate risk is to protect the health and safety of the exploration project team and, if possible, collect baseline climate and weather information.

It is not necessary to undertake a detailed climate risk assessment during the exploration stage, but rather a high-level understanding of where weather events pose risks to activities or people and whether more detailed assessment is warranted.

Phase 1: Identify and Assess Opportunities

During the phase when the technical and economic viability of exploiting the resource is determined, it is important to understand the climate context (current baseline and future projections), within which the proposed project might be developed, and the associated risks for the project. The objective of considering climate risks during this phase is to ensure that climate and weather risks associated with construction, operation, closure, and post closure at that site do not materially impact the viability of the concept. Much of the information required for this assessment could be obtained through the ESIA process.

The activities that could be conducted during this phase include characterizing the climate context for the project, identifying climate risks, identifying key project decisions affected by climate and weather, and identifying further research requirements.

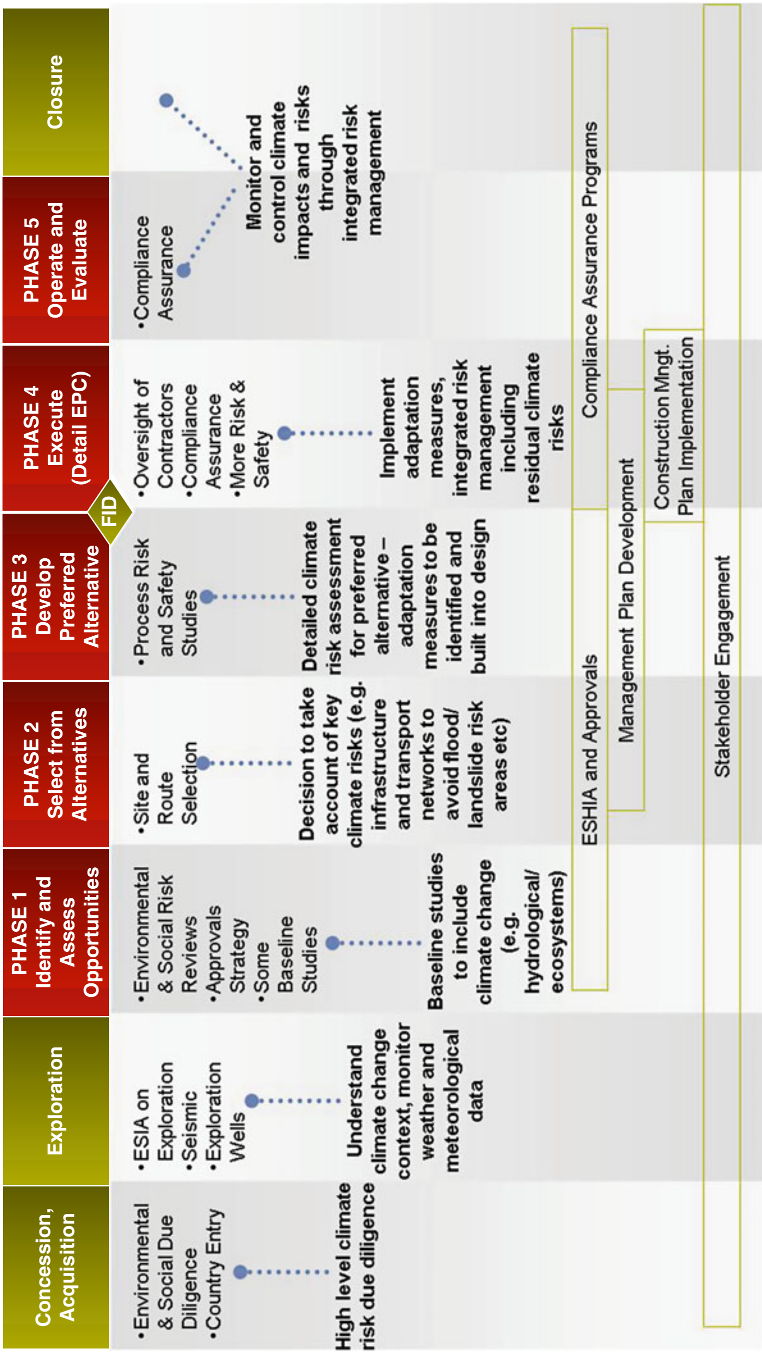

Fig. 7 Overview of climate change activities within the project development cycle

Phase 2: Select from Alternatives

Phase 2 provides the widest scope for the generation, investigation, and elimination of alternatives. At this stage, the purpose of assessing climate risks and adaptation measures is to inform the generation and elimination of project options such that the optimal option (in terms of all technical, commercial, and sustainability aspects, including the climate risk profile) is selected to be put forward for consideration. In addition, adaptation measures to mitigate key risks should be identified for each alternative. Climate risks and opportunities should be assessed at this stage to the greatest possible level of detail for the site as well as the supply chain (based on the information available at that time, much of which could be generated during the ESIA process).

The work undertaken during Phase 1 provides a base upon which to assess risks from extreme weather and climate change in further detail during the option identification and appraisal process in Phase 2.

Phase 3: Develop Preferred Alternative

During Phase 3, the alternatives selected and approved at the end of Phase 2 are refined and finalized to a level of detail and accuracy normally associated with project execution plans.

The purpose of climate risk and adaptation assessment at this stage is to ensure that the "Final Investment Decision" (FID) is based on a design that includes all necessary measures to optimize the climate risk profile of the operation.

Should any new information arise at this stage that raises the climate risk profile of the selected alternative to an unacceptable level, this should be flagged as soon as possible. In this situation, adaptation measures should be identified to bring the climate risk level down to acceptable levels.

Phase 4: Execute and Phase 5: Operate and Evaluate

Once the project design has been finalized and activities turn to construction and operations, the adaptation measures identified need to be implemented and residual risks (i.e., those which cannot be prevented through design such as flooding exceeding thresholds) should be managed through the company's integrated risk management procedures as described above.

It is also important that weather data is monitored on a regular basis and the impact of extreme events tracked in order to feed into risk registers and for additional adaptation measures/controls to be implemented as required during the life of the operations.

Closure

Given the long-term nature of climate change, a company's liability in relation to climate change may continue post closure. For example, in the mining sector an increase in rainfall may threaten the integrity of tailings storage facilities or increase runoff through waste rock leading to contamination of groundwater sources. A hydropower plant may experience generation difficulties during droughts or periods of particularly heavy rainfall.

ESIA Practitioner Guidance for Including Climate Risk and Adaptation in ESIA

Climate change presents a new dimension to the traditional impact assessment conceptual framework in that it implies a dynamic rather than static baseline from which project impacts occur. This means that climate change, occurring irrespective of the project, may have the effect of altering the overall significance or magnitude of project impacts on the human and natural environment. It is critical to capture both elements through the impact assessment and project planning process.

In order to ensure that climate change is effectively incorporated within the capital project impact assessment process, the ESIA project management team should follow the steps below to ensure that the need for and the level of detail required in a climate change risk and adaptation study is carefully considered.

Step 1: Climate Change Vulnerability Screening and Scoping

During the scoping stage, it is important to ascertain the degree to which climate change is a significant consideration in project design and impact assessment. Key questions to answer at this stage are:

- Is the project climate dependent?
- Is the project climate vulnerable?
- Are communities and local ecosystems climate vulnerable?
- Could project impacts exacerbate vulnerabilities?

The project developer, and ESIA team, should consider each of these questions in the context of each phase of the project life cycle, taking into account current climate variability as well as likely future trends in the project's location. "Climate dependency" refers to the degree to which the project requires resources or operating conditions to function which may become more scarce or less predictable because of climate change – for example, reliable freshwater supply (a requirement for most industries), a specific temperature range (such as for agricultural development projects or tourism ventures), a specific sea level (such as for a port), etc. "Climate vulnerability" encompasses the elements of climate dependency but also includes consideration of whether a project's assets or productive capacity may be directly affected by climate related hazards which may become more frequent or intense under future climate scenarios. Such effects may include more frequent or intense floods, hurricane force winds, storm surges, etc.

This will necessarily be a high-level initial assessment but will provide an indication of the potential importance of climate change impacts on the future operations of the project and therefore the level of analysis required during the ESIA process.

The climate change specialist study and ESIA proposal should be drafted based on the findings of these deliberations.

Step 2: Include Climate Change in Specialist Studies

Each project will have its own unique issues relating to the proposed activities, and ESIA specialists are well placed to investigate how climate change might influence the impacts identified during the ESIA process.

While it is possible to conduct a high-level – stand-alone – climate risk and adaptation specialist study, it is recommended that all specialists providing input into the ESIA process are requested to assess the potential impact of climate change on their findings. This will ensure site-specific analysis of the potential impacts to the project, environment, communities, and ecosystem services.

Examples of the types of analysis which could be undertaken include:

- Surface and groundwater hydrology studies to look at how changing precipitation and evaporation might affect stream flow and groundwater recharge
- Biodiversity studies to look at how local ecology and agricultural practices might change with changing temperature and precipitation patterns to feed into decisions on rehabilitation, resettlement, and impacts on local community livelihoods
- Flood risk assessments, including research on the frequency and severity of historical flooding in the area, the influence of topography on flood prone areas within the site, and the projected trends for flood events in light of predicted climate change
- Ecosystem services assessments to consider how the availability and use of services might change in the future and the associated impacts

Where possible, the first phase of the climate risk and adaptation approach outlined in Fig. 8 should be undertaken at the very start of the ESIA in order for the findings to feed into the work of the specialists – i.e., hydrologists will be able to model increase/decrease in precipitation into water balance/stream flow/groundwater assessments.

Step 3: Summarize Climate Change Risks, Vulnerabilities, and Adaptation Measures In Line with IFC Requirements

If the project is required to comply with the IFC Performance Standards or Equator Principles, it is important to ensure that the ESIA covers all of the requirements on climate change risk, impact, and vulnerability included in the 2012 IFC Performance Standards and their accompanying guidance notes.

In this final step, a report should be prepared summarizing the climate change context for the project and collating the information gathered in the specialist

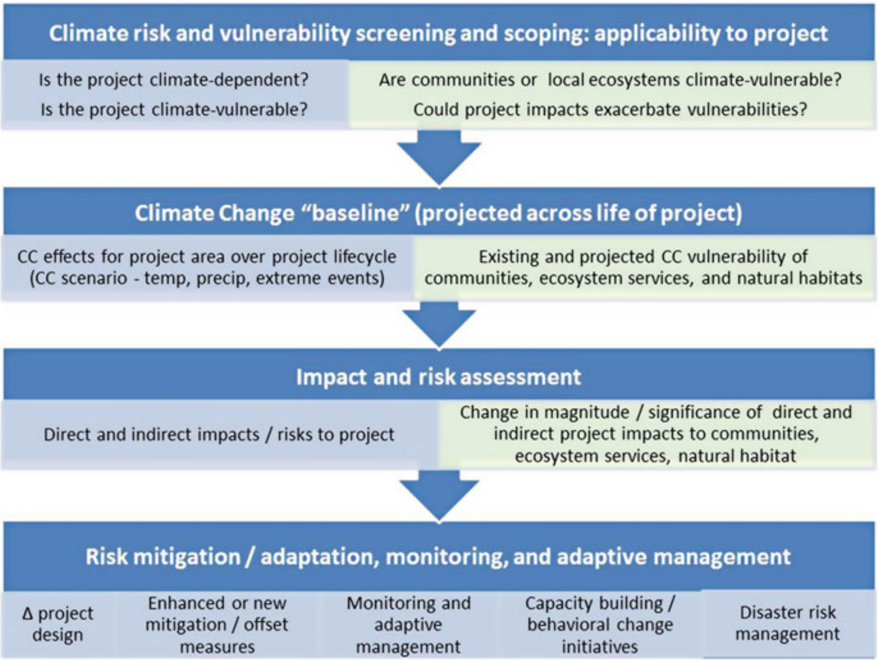

Fig. 8 An approach to incorporating climate risk and adaptation in the ESIA process

studies and any stand-alone analysis required to ensure that the impact of climate change on the project is fully understood and discussed within the ESIA. The report could follow the basic framework outlined in Fig. 8.

Conclusion

As was described in this chapter, understanding and managing climate risk and adaptation, at a facility or project level, is central to ensuring business continuity and reducing costs. This is particularly important in relation to utilities, infrastructure, and the extractives sector (i.e., mining and oil and gas activities). Furthermore, building resilience to climate change and incorporating adaptation measures into project design, as well as impact management programs – such as ESIAs –, is now being mandated by a growing number of financial institutions, as well as national and state governments.

Climate change can also present a new dimension to the traditional impact assessment conceptual framework in that it implies a dynamic rather than static baseline from which project impacts occur. This means that climate change, occurring irrespective of the project, may have the effect of altering the overall significance or magnitude of project impacts on the human and natural environment.

In order to ensure that climate change is effectively incorporated within the capital project impact assessment process, the ESIA management team of the project can follow the steps outlined in this chapter to ensure that the need for and the level of detail required in a climate change risk and adaptation study is carefully considered. Furthermore, incorporation of climate change assessment in the existing risk management and impact assessment procedures could help enhance resilience in a more efficient and effective manner than implementing stand-alone procedures in parallel.

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The Role of Climate Services in Adapting to Climate Variability and Change

Paul Bowyer, Guy P. Brasseur, and Daniela Jacob

Contents

Abstract

Adaptation to climate change has risen up the political agenda in recent years, as the realization that we are committed to at least some level of climate change over the next few decades has been acknowledged. It is also the case that a range of different economic sectors, both public and private, increasingly recognize the need for, and importance of, adapting to climate change and the need to manage

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their climate risks. Adaptation to climate change is a complex issue, and successful adaptation will depend on the intelligent use and combination of a range of different factors, including scientific, organizational, social, and governance structures. This chapter focuses on the role that climate services can play in helping organizations and societies adapt to climate change and variability. It provides an overview of the key components of climate services and details the essential functions which climate services must develop, in order to fully play their role in supporting adaptation decisions and thus, helping society adapt to climate change.

Keywords

Climate services • Adaptation • Decision support • Risk management • Climate modeling

Introduction

There is an increasing demand from society and governments to have access to information related to weather and climate to assist in the development of adaptation responses to climate risks (Parry et al. 2007; DAS 2008; Cane 2010). This demand places greater importance on the need to support and develop appropriate institutions and resources and has helped spur the development of climate services and climate service centers (Barron et al. 2001; Miles et al. 2006; Visbeck 2008; Tollefson 2010). Climate services may be defined as the provision of timely, decision-relevant, actionable, science-based information, and guidance on climate variability and change, and the associated environmental and social impacts, to assist decision makers (users) in the public and private sector in the development of responses to manage their climate risks. The provision and development of such information represents a considerable challenge, and is one that cannot be met by the resources and capacity of one organization alone, and indeed, in some cases might require international collaboration. To develop actionable climate information that can inform adaptation decision making is a challenge for society in general and climate research and climate services in particular. Recognizing this challenge, various international initiatives have been developed recently to support the provision of climate services, in particular the Global Framework on Climate Services (GFCS) from the World Meteorological Organization (WMO), the Climate Service Partnership (CSP), and the Joint Programming Initiative (JPI). The main aim of the GFCS is to support strong interaction between science and research on the one hand, and communication with stakeholders on the other, to ensure that the climate information is both actionable and usable (Cash et al. 2003; Meinke et al. 2006; Lemos and Rood 2010; Lemos et al. 2012). Additionally, the CSP and JPI go further and advocate for the co-creation of knowledge between users and providers of climate services.

Climate services information comprises a range of products and services, including climate observations, climate model forecasts, predictions and projections of possible future climates at a range of timescales (months, seasons, decadal, and centennial), projected environmental and societal impacts, vulnerability and risk assessments, and decision support tools, among others. As such, climate services can offer an end-to-end analysis and presentation of information relevant to adaptation decisions; they will require strong partnerships and networks between all actors concerned and will support the co-production of knowledge on climate-related issues. The disciplinary breadth required from climate services therefore needs to go far beyond that offered by national meteorological and hydrological services (NMHSs), although clearly these organizations have an extremely important role to play. Climate services should therefore be developed and provided by inter- and transdisciplinary teams including climate, environmental, social, and political scientists, economists, and risk and decision theorists, as well as stakeholders.

Climate information needs to incorporate strong communication channels between decision makers and knowledge providers, to ensure knowledge exchange, facilitate two-way dialogue and shared learning, particularly in relation to understanding user needs and existing knowledge and the limits and capabilities of the science-based information in meeting them.

This chapter provides a discussion of the various elements that are likely to be central to the successful development of climate services, with particular emphasis on the use of climate modeling to support adaptation decision making. The focus is therefore on summarizing key developments, the current state-of-the-art and future prospects for developing seasonal and decadal climate model predictions, and the use of multi-decadal projections of changes in climate. In addition, the need for effective user engagement, and the co-production of knowledge, is argued. Moreover, the institutional challenges including funding of climate services and the role of the public and private sectors in developing climate services are discussed. The chapter finishes with a discussion of the future direction of climate services and conclusions on the current state of climate services and their role in enabling adaptation responses.

Providing Decision-Relevant Climate Information

Climate information can be and has been used in both top-down “scenario led” approaches and bottom-up vulnerability approaches to climate risk assessment (Carter et al. 2007; Wilby and Dessai 2010; Weaver et al. 2013; Stern et al. 2013). The top-down approach has been criticized for not providing decision-relevant information, owing to the fact that the analysis is not structured around valued objectives that a given organization may have and also because the range of uncertainty that can be generated may often overwhelm decision makers (Wilby and Dessai 2010). The discussion presented here is based on the methods that are used in the top-down approach, where global and regional climate models are used in connection with impact models. However, it should be stated that the use of model information in itself does not mean that a top-down approach has been followed, and the limitations of this approach for providing useful information for developing adaptation strategies is acknowledged. Rather, an explicit recommendation for incorporating the use of climate model information into a bottom-up vulnerability or risk-based approach to developing adaptation strategies is made, whereby climate information is used in relation to answering specific questions about system performance. In doing so, a link between the conventional top-down and the bottom-up approaches is made (Mastrandrea et al. 2010; Weaver et al. 2013). This conceptual difference between the top-down and bottom-up approaches is illustrated in Fig. 1.

Uncertainty and Predictability in Model-Based Information

This section reviews the production of model-based climate information at the seasonal to decadal timescales and multi-decadal or centennial projections. The way in which this modeled information can be used in supporting adaptation decision making is discussed in (Bowyer et al. 2014 this volume).

The development of future climate information based on global climate model (GCM) outputs is confronted by three sources of uncertainty related to internal variability, uncertainty in the climate response to radiative forcing (model spread in Fig. 2a), and greenhouse gas scenario or emission uncertainty (scenario spread in Fig. 2a). The relative importance of these different sources of uncertainty varies with the timescale considered. As one moves through time, uncertainty increases (Hawkins and Sutton 2009; Kirtman et al. 2013). This has implications for the kind of methodological approaches that are employed to provide useful future climate information at different timescales and the way in uncertainty in each different source needs to be sampled.

For the development of future climate information at monthly, seasonal, and interannual timescales, internal variability is the main source of uncertainty, while at decadal timescales model spread and internal variability (e.g., dynamical modes such as El Niño) dominate, with scenario uncertainty playing a relatively minor role. At multi-decadal to centennial timescales, scenario spread is the main source of uncertainty. The skill of model predictions and projections is determined in large part by how well the relevant processes can be represented in the models and how well the different sources of predictability in the climate system can be incorporated. These sources of predictability at different timescales, and in the different Earth system components (ocean, land, atmosphere, cryosphere), are summarized in Fig. 3. Because of the relative importance of different sources of uncertainty at the monthly to seasonal and interannual timescales, the nature of the problem is one of initialization (Shukla 1998), whereas at the centennial scale it is the representation of external forcing (scenario spread) and the climate response to this. At the decadal timescale the problem is thought to be one of initialization and external forcing (Meehl et al. 2009). It is important to state that although novel approaches to initializing the climate system may reduce the uncertainty attributable to internal variability, there will always be uncertainty as a result of the chaotic nature of the Earth's climate system.

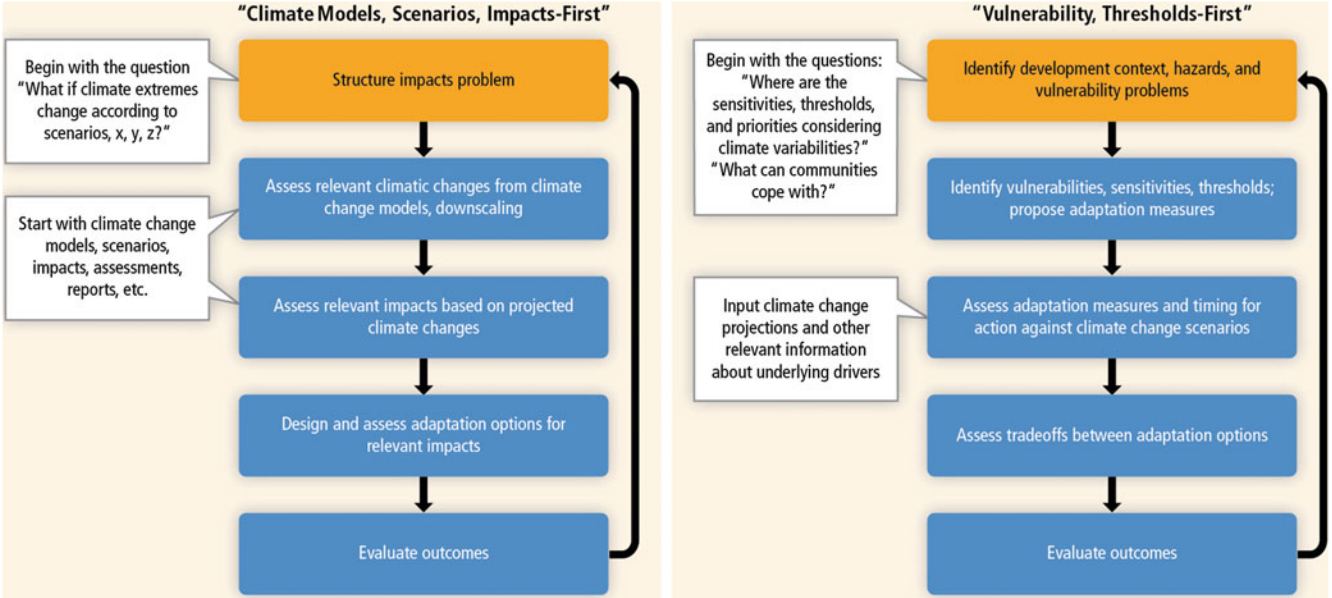

Fig. 1 Top-down scenario, impact-first approach (*left panel*), and bottom-up vulnerability, thresholds-first approach (*right panel*) – comparison of stages involved in identifying and evaluating adaptation options under changing climate conditions (Source: Lal et al. 2012)

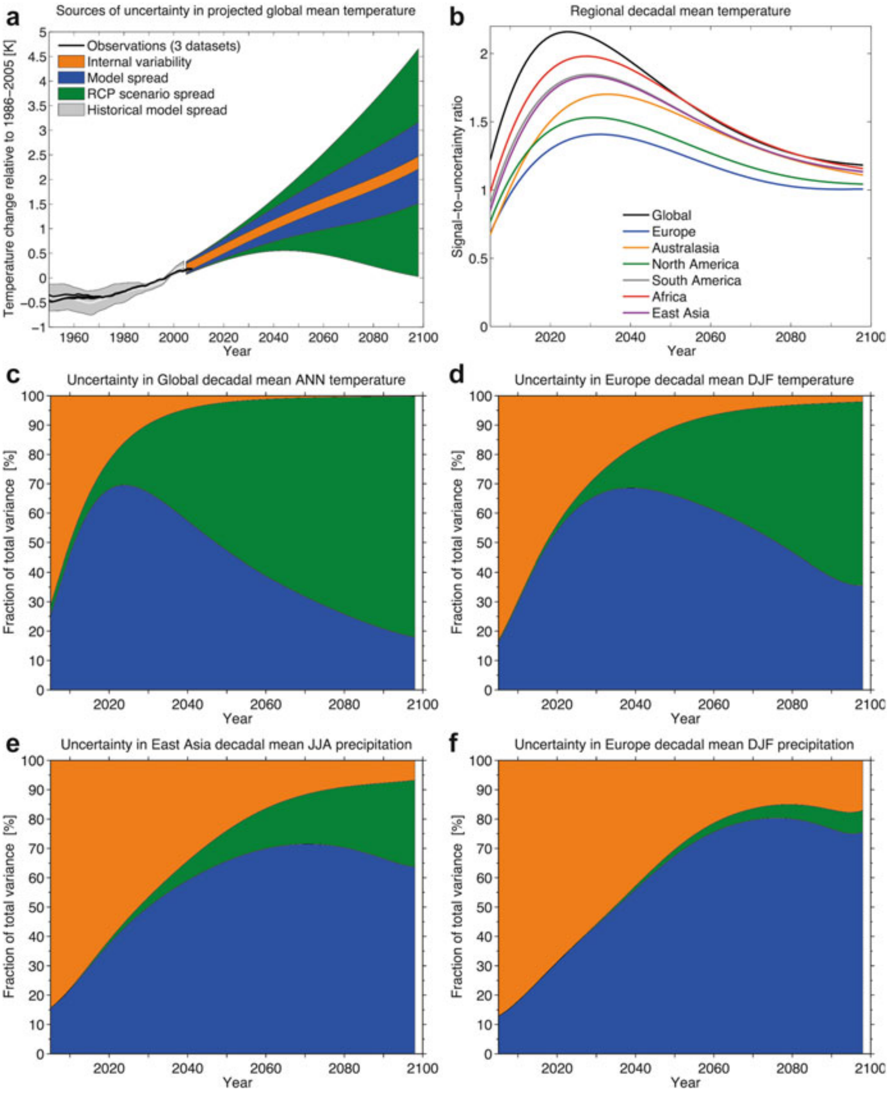

Fig. 2 **Sources of uncertainty in climate projections**. Sources of uncertainty in climate projections as a function of lead time based on an analysis of CMIP5 results. (**a**) Projections of global mean decadal mean surface air temperature to 2100 together with a quantification of the uncertainty arising from internal variability (*orange*), model spread (*blue*), and RCP scenario spread (*green*). (**b**) Signal-to-uncertainty ratio for various global and regional averages. The signal is defined as the simulated multi-model mean change in surface air temperature relative to the simulated mean surface air temperature in the period 1986–2005, and the uncertainty is defined as the total uncertainty. (**c**–**f**) The fraction of variance explained by each source of uncertainty for global mean decadal and annual mean temperature (**c**), European (30°N to 75°N, 10°W to 40°E) decadal mean boreal winter (December to February) temperature (**d**) and precipitation (**f**), and East Asian (5°N to 45°N, 67.5°E to 130°E) decadal mean boreal summer (June to August) precipitation (**e**) (Source: Kirtman et al. 2013)

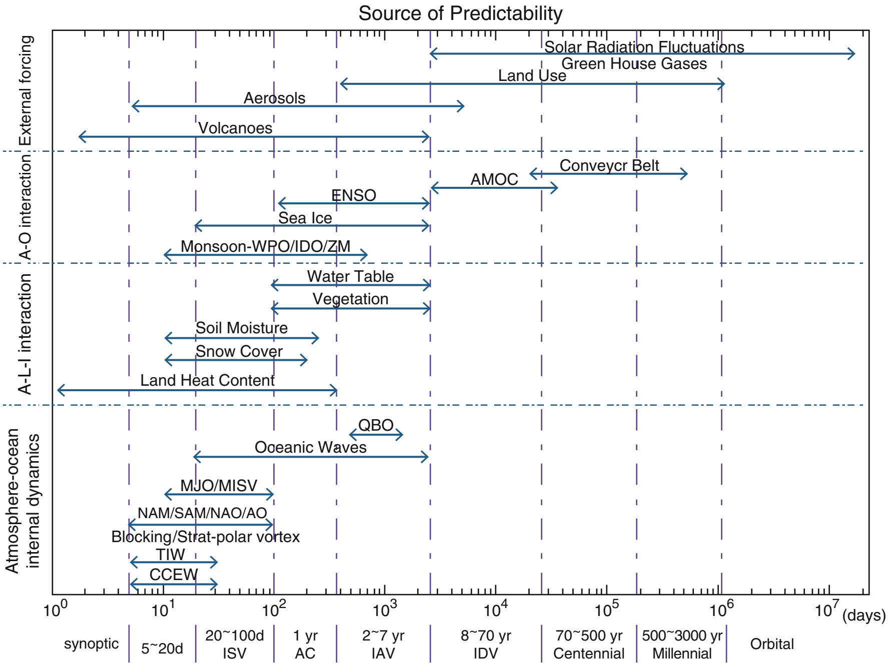

Fig. 3 **Sources of predictability in climate modeling**. Processes that act as sources of ISI climate predictability extend over a wide range of timescales and involve interactions among the atmosphere, ocean, and land. CCEW convectively coupled equatorial waves, TIW tropical instability wave, MJO/MISV Madden–Julian Oscillation/Monsoon intraseasonal variability, NAM Northern Hemisphere annular mode, SAM Southern Hemisphere annular mode, AO Arctic oscillation, NAO North Atlantic oscillation, QBO quasi-biennial oscillation, IOD/ZM Indian Ocean dipole/zonal mode, AMOC Atlantic meridional overturning circulation. For the *y*-axis, “A” indicates “atmosphere,” “L” indicates “land,” “I” indicates “ice,” and “O” indicates “ocean” (Source: Adapted from NRC 2010)

Climate information developed at monthly to seasonal to interannual timescales currently derive their skill from the inclusion of in situ and remotely sensed observations of the initial state of the ocean surface and subsurface and the atmosphere (Goddard et al. 2010; Stockdale et al. 2010). These observations are assimilated into coupled atmosphere–ocean climate models, thus sampling the main source of uncertainty in climate predictions at this timescale (Palmer and Anderson 1994; Stockdale et al. 1998; Palmer et al. 2004; Rodwell and Doblas-Reyes 2006; Weisheimer et al. 2009). The skill of seasonal forecasts varies temporally and spatially, however, which is determined by the persistence and power that an initialization contains for making predictions in different areas of the world. To date, the greatest skill in seasonal forecasting has been demonstrated over tropical regions (Palmer et al. 2008; Lavers et al. 2009; Weisheimer et al. 2009), though this skill also changes with the climate variable concerned and also the time of year. Moreover, this skill is greater for climate variables over the ocean than the land surface, raising questions about the usefulness of such forecasts for informing decision making and underlining the importance of reporting skill scores or measures of reliability with the products.

On the basis that initialization at monthly to seasonal and interannual timescales contains predictability about the climate system, there has been much recent interest in combining the initialization approach with external forcing, to develop model predictions at the decadal timescale (Haines et al. 2009; Meehl et al. 2009; Keenlyside and Ba 2010). This is a timescale for which there is burgeoning demand, owing to the fact that this is often a timescale which is more closely aligned with the planning horizons of a number of adaptation decisions (Cane 2010). Developing decadal prediction systems has duly seen a significant amount of research over the last few years; however, the use and availability of such predictions remains very much in its infancy, and the approach overall is still very much experimental (Meehl et al. 2010; Tollefson 2013). Initializing with observations of the ocean and atmosphere, and using prescribed radiative forcing, has been shown to improve decadal prediction of global surface temperature anomalies (Smith et al. 2007). Work initializing with information on sea surface temperature, and prescribed radiative forcing, has shown improved surface temperature prediction over the North Atlantic (Keenlyside et al. 2008; Pohlmann et al. 2009). These latter two studies did not, however, report increased skill when hindcasting global mean temperature. Other research has shown that initialization contributes little additional predictability compared to changes in external radiative forcing (Troccoli and Palmer 2007; Meehl et al. 2010; Hermanson and Sutton 2010). Furthermore, there is some evidence to suggest that under a warming world, the predictive power of initialization will decrease in decadal temperature and precipitation predictions (Boer 2009).

Multi-decadal or centennial projections of climate change have seen widespread use and application in the adaptation decision-making process, whether this be for the identification of possible climate risks or more detailed studies of what future changes may mean for various economic sectors (Vermeulen et al. 2013). Being able to test or validate multi-decadal projections is clearly very difficult, as one would have to wait for a number of years to be able to test this (Allen et al. 2013). Often what is done to test the various different models is to use hindcasting and use an error statistic to represent how skillfully a given model is able to represent recent and historical climate changes. This is a necessary but not sufficient condition for the use of multi-decadal climate projections in adaptation decision making. This, in addition to the long timescale that is being dealt with, means that there are very large uncertainties associated with the use of these projections. This raises an issue as to how best, or most suitably, to make use of such projections in supporting adaptation decisions (Weaver et al. 2013).

Clearly, much more research is required in monthly, seasonal, interannual, and decadal prediction to establish the reliability of these approaches (Hurrell 2008), such that they may prove suitable for use in informing adaptation decision making. The research community is currently addressing this through such activities as the WCRP/ CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP). In addition, the pursuit of the seamless prediction system, whereby processes relevant to sources of predictability are represented at all scales, is one that would be of enormous benefit to climate services in making reliable and useful information available to decision makers (Rodwell and Palmer 2007; Lavers et al. 2009). This vision is one that will require enormous effort and resources, both human and financial (Shukla et al. 2010). Similarly, large investments in land-, ocean-, and space-based observing systems need to be maintained and improved through the work of programs like GCOS, GOOS, GMES, and the Group on Earth Observations (GEO). The assimilation of, for example, subsurface ocean heat content from ARGO floats (Roemmich et al. 2009) will likely yield further advances, but this will also require advances in data assimilation schemes, if potential improvements are to be realized.

Downscaling Model-Based Information

Regardless of the timescales and methods used to develop predictions or projections from GCMs (usually at a spatial resolution of 100–300 km), some form of downscaling will be necessary to provide climate information at the regional to local scales (typically less than 50 km), suitable for use with impact models (Wilby and Wigley 1997; Fowler et al. 2007).

Downscaling will be needed for a long time in the future since, even with access to the most powerful computer facilities, it is unlikely that global climate models will soon provide information at a spatial resolution that is sufficiently high to meet the needs of most impact models.

Given the diversity of uses of regional scale information, it seems sensible that both statistical and dynamical downscaling approaches are adopted, as the relative merits of each are better suited to some applications than others (Déqué et al. 2007; Jacob et al. 2007; van der Linden and Mitchell 2009). For example, dynamical downscaling is more suitable in areas with complex topography and where the local observational data are sparse. In contrast, operational applications where the time frame of analysis is relatively short (e.g., seasonal forest fire risk) may dictate that more computationally efficient statistical downscaling is used. Further, it is currently not possible to say conclusively that one method is better than another.

In light of the foregoing discussion, the choice of downscaling method should be guided by the climatic region, local topography, variables of interest, and application to which the results are to be put. However, regardless of which method is used to downscale, all results will ultimately be limited by the accuracy of the driving boundary conditions supplied by the GCM, and as such, research priorities in global modeling are also relevant to the regional models (Schiermeier 2010).

Model Quality Assessment

If users are to apply climate and impact model information to their adaptation decision-making process, they will rightly ask and need to know: are the models any good? Can they be trusted? Which one should I use? Climate service providers need to be able to answer these questions. This issue is related to model skill, and the development of model quality metrics, and is an increasingly important research area (Glecklers et al. 2008; Knutti et al. 2010).

Model skill or performance is typically evaluated with respect to how closely the model simulation corresponds to observations, quantified via some error statistic, e.g., RMSE (Murphy et al. 2004; Reichler and Kim 2008; Flato et al. 2013). This approach is suitable for quantifying the skill of monthly to seasonal forecasts. However, for decadal to centennial timescales, this approach is less suitable, due to a lack of sufficient observations at these timescales. Moreover, it doesn't automatically follow that a model that performs well with respect to past and recent climatology will have future predictive skill. Although there is some evidence that strong relationships do exist between past and future trends (Boer 2009), in the main, this is not the case (Knutti et al. 2010). The evaluation of model performance at decadal (and longer) timescales thus needs to be evaluated against longer timescale data (palaeoclimate data), and how well key climate processes and feedbacks are represented, in addition to observations, if a broader level of evidential support is to be established for the credibility of models at these timescales. Moreover, these evaluations need to be made over a number of different climate variables and for different statistical properties (e.g., mean state, variability amplitude) and at a range of time and space scales.

Having calculated model performance metrics, how are users able to make sense of them in determining model quality? Currently, there is no clear set of metrics which are commonly agreed to serve as useful indicators of overall model quality. Accordingly, it is important when trying to distinguish between different models that more than one metric is used to establish model quality, because a model that simulates one variable well may simulate other variables less well. Therefore, a range of different metrics should be used, and the actual assessment of model quality should be determined on a case-by-case basis, according to the performance of a given model with respect to the key variables and processes that are key to the accurate simulation of the intended application (Wilby and Harris 2006; Flato et al. 2013). This also raises the question of which impacts models are most accurate and thus suited for purpose? This reinforces the importance of quantifying uncertainty along the model chain from GCMs through to the impacts models themselves.

Clearly, there is a long way to go before a commonly agreed set of metrics for evaluation of model quality can be determined and that are application specific. The challenge of communicating these metrics to users, however, will require that the metrics are relatively simple to calculate.

Communication and User Engagement Challenges

For climate services to be useful and usable, i.e., provide decision-relevant information, it is imperative that a sustained two-way dialogue is established between providers and users to support the co-generation of knowledge (Lemos et al. 2012).

The best science in the world may "sit on the shelf" and be irrelevant, if users are not able to make use of the knowledge. There has been research to suggest that there are three essential elements to ensuring "actionable" climate knowledge (Cash et al. 2003; Meinke et al. 2006). These essential elements are *saliency* (the perceived relevance of the information), *credibility* (the perceived technical quality of the information), and *legitimacy* (the perceived objectivity of the process by which the information has been produced). A related issue to the development of actionable knowledge is that the usability of any products developed should integrate smoothly with existing management structure systems (Lemos et al. 2012). This provides a useful framework within which to discuss user engagement in relation to climate services.

To ensure salient climate information is developed, demands that the climate-related problems faced by different economic sectors are well known and explained before product development is embarked upon. This requires the gathering of key people and decision makers from the different economic sectors, together with scientists and other experts, to engage them in a discussion and to learn about their problems. This engagement should be a proper discussion of the issues and possibilities for development of climate products, such that the process is much more than simply asking users what they want. A good example of where such an exchange has taken place is the US Global Change Research Program (USGCRP), whereby a large number of "Listening Sessions" have been held to garner the views of key stakeholders in helping to shape the USGCRP, thus ensuring user-relevant research programs, and user buy-in to subsequent developments. Institutes developing climate services will require to implement these and similar kinds of mechanisms. Furthermore, saliency will relate to the provision of easily accessible and understandable products.

Credibility in the development of climate information and products demands that efforts are made to report and inform on the reliability of different products, both in relation to the methodological approach and the subsequent model results. This underscores the importance of sustained research efforts in the development of model and product quality metrics. Establishing credibility in the products also requires that the institutes and centers that are developing and delivering products are themselves credible. This relates to being open and honest in discussions and genuinely informing and building capacity with users. This will help to build trust, which in turn will aid credibility.

The legitimacy of the process by which climate information and products are developed is related to the way in which the needs of different users have been considered and realized in the final product. This involves having a sustained, mature, constructive, two-way dialogue between users and providers that facilitates the co-production of knowledge, where users can make their needs clear and providers can explain the status of the science to meet these needs, and the implications for possible product development. Only by doing this will users buy into the information and products that are subsequently developed. This issue of legitimacy also relates to the perceived independence of the organizations developing or delivering the climate products and is an issue related to the kind of organizational and institutional framework within which climate services are situated and associated funding models. Ensuring actionable products are delivered will thus demand a large investment of time and effort on the part of both users and providers, and developing this partnership will be critical to the success of climate services.

Another key aspect of user engagement is open and honest discussion of the limitations associated with various climate products and their suitability for, and practical use in, decision making and policy development (Lempert et al. 2004; Lemos and Rood 2010). This discussion of limitations should be accompanied by the provision of advice, training, and genuine knowledge exchange between experts and users with real-world problems. Educating users about limitations, and the appropriate use of observations and climate model information, provides an advisory and consultative function for climate services, which, done well, should reduce the chance of unrealistic expectations on the part of users. Successful user engagement will also depend on the use and development of clear and unambiguous language, so that experts and non-experts alike can understand each other. Accordingly, effective communication is a major task for climate services. Moreover, close collaboration between users and climate services will be essential for the identification of critical thresholds, current coping ranges and vulnerability, and how adaptive measures can help manage current and future climate risks (Jones and Mearns 2005).

Institutional and Organizational Challenges

While a number of developments are underway in developing climate services, there are various challenges that need to be overcome, if climate services are to play their full role in supporting adaptation decision making. To be successful, climate services cannot be isolated from the research community and user needs. The quality of the products to be developed by these services is directly dependent on advances made by the fundamental and applied science. Strong ties between climate services and research institutions are therefore essential.

Climate services make use of information derived from observations and model projections. It is perhaps insufficiently stressed that there is a need to improve access to data and to develop a more integrated monitoring and data management system (Stern et al. 2013). At the same time, the development by the international research community of the next-generation high-resolution Earth system models (Shapiro et al. 2010) and analysis systems requires the development of interdisciplinary teams and dedicated access to state-of-the-art supercomputers. In parallel to these scientific and technical developments, more resources will have to be invested in the analysis of observation and modeling data (to ensure quality control), the development of integrated assessments, risk management and in economic evaluations of adaptation policies.

The provision of suitable infrastructure for running the very high-resolution Earth system models, and handling the very large data sets that will be generated, is an area where the private sector has an important role to play, in ensuring that climate services can be successfully developed. In addition, significant resources will need to be invested in ensuring that these data sets are translated into products and information that are easily accessible and understandable to users. This development will require the close collaboration of scientists and users, and this is a function that will likely best be performed by climate service centers and similar organizations.

The private sector will also need to collaborate as users. The climate risks that an organization may face will vary with the type of business and location. Tourism, energy, agriculture, and water, for example, operate where supply, demand, and price fluctuate considerably with weather conditions. Investments are considerably affected in areas prone to frequent drought, flooding, and other extreme events. In the long term, proactive responses of business to climate-related risks and the early implementation of adaptation measures will likely confer competitive advantage. The information provided by climate services must be objective, legitimate, authoritative, and relevant and thus independent of economically driven pressures. Transparent interactions with the private sector, however, must be established so that decision makers better appreciate climate risks in their business activities and thus their relevance for the success of their business (Ruth 2010).

The financial arrangements in support of climate services must ensure the intellectual, economic, and political independence of the groups generating knowledge and disseminating information. Sustained public funding is therefore a requirement for many of the activities conducted by climate services. The development of constructive interfaces between the services and the users remains, however, a challenge. A possible solution is to create small start-up private companies that work directly with businesses and corporations, regional governments, municipalities, and other local communities (Brooks 2013). These companies would develop joint projects with their customers, address their specific needs, and provide tailored information to facilitate future planning and investments.

Even with such institutional arrangements that clearly separate the respective roles of the public and the private sectors, communicating complex and evolving information in terms that are easily understood remains a challenge. There is a long way to go between the production of scientific knowledge by the research community and, for example, the implementation of adaptation measures by the different economic sectors. The psychological and procedural aspects of the communication process also need to be considered (Pidgeon and Bischhoff 2011). It is therefore crucial to develop efficient and targeted communication channels that highlight the economic benefits for corporations and other entities to immediately prepare themselves for climate change.

Finally, the international dimension of climate services is of crucial importance. Observation infrastructures operate at the local to global scale, and data exchange is of primary importance. Supercomputing facilities may also need to be shared between different research and operational groups from different countries. In addition, in the same way that the national meteorological services from all countries cooperate, it is important that similar institutional partnerships be established to deal with climate information, risk assessments, and adaptation policies. One way in which this could be organized would be to have five or six regional centers distributed around the world, with the dedicated focus of developing research to support climate service activities internationally. International discussions should lead to a better assessment of the demand from society, the need and role of climate services, sustainable funding mechanisms, quality data and information, targeted scientific research and innovation, systematic knowledge exchange, and capacity building.

Conclusion

The development of climate services that play their full role in helping society to respond and adapt to climate variability and change faces many challenges. At the heart of climate services is strong communication between users and providers, ensuring that actionable climate information is delivered. This will only be possible, with a committed and concerted effort on the part of users in the private and public sectors, researchers, government, and society in general. This effort will only be assured when the size and urgency of the adaptation challenge is widely recognized and acted on. This is likely to require some form of legislation, regulation, and incentives to promote a response, e.g., in ensuring that building standards and codes require that possible future climates are considered in the design phase.

For climate services to be successful, they will need to demonstrate that they can meet the needs of users and thus contribute value to adaptation decisions. The use of climate observations and centennial timescale model projections has already demonstrated their value in a number of adaptation responses. For seasonal and decadal timescale model predictions to also provide value to users, however, clearly requires much more research. At present, the state of the science in seasonal, interannual, to decadal predictions is such that it may well be several years and possibly decades before scientifically reliable products can be delivered the world over, at all times of year, and for a wide range of climate variables and spatial scales. Despite this, there are already operational seasonal forecasts generated by, for example, the European Centre for Medium Range Weather Forecasting (ECMWF) and the National Center for Environmental Prediction (NCEP) in the USA, which are applied to a range of activities and from which users derive value.

Regardless of the timescale, deriving value from climate information will need to be patiently constructed and will only be possible through the close collaboration, shared learning, and knowledge exchange between users and providers over a sustained period of time (Brooks 2013).

With respect to downscaling to regional scales, there is much research still to be done in both the global and regional modelling communities. This will likely be achieved through increased resolution and better process representation. In addition, advances in the development of model quality metrics will be needed for a range of different application areas, before users can make a truly informed choice on the types of products they may like to make use of and the range of uncertainty to be expected. Clearly, these issues demand significant investment in fundamental research.

The way in which uncertainty is dealt with is a major issue for making decisions in relation to adaptation. Given the number of different models and the cascade of uncertainty from the global to regional scales through impact models, and the possibility that uncertainty can increase as models become more complex, users need to carefully structure their analyses and assessments based on a careful consideration of the decision context. In addition, advances are needed in the development of dynamically coupled and integrated assessment models, to more realistically simulate the real world, and the interactions between climate, socio-economics, and the environment (Füssel 2010; Nobre et al. 2010). Given the large range of uncertainty from models, together with the fact that there are many uncertainties that are not quantified, necessitates the need for robust adaptation, where decision makers seek flexibility and strategies that perform well across a range of different future climates, rather than striving for optimality (Bowyer et al. 2014 this volume, Weaver et al. 2013).

Climate services offer much potential to help support adaptation to climate variability and change. There is strong institutional support at the global level through the GFCS, CSP, and other initiatives, and this is being accompanied by strong support in a number of countries around the world. Sustaining these activities will require long-term commitment and significant investment in fundamental research, observation platforms, institutions, user engagement, and capacity building, if this potential is to be realized.

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The Role of Wetlands in Mitigating the Effect of Climate Change in Nigeria

Nasiru Idris Medugu

Contents

Abstract

This chapter reviews the place of wetlands in climate change within the overall frame of environmental resource planning. This is against the background of the importance of wetlands as environmental resources which have been described as the kidneys of the landscape as a result of its hydrological and chemical functions and as atmospheric carbon sinks which stabilize the climate. The study reviewed mitigating and adapting measures in literatures that may be adopted in Nigeria in order to enhance the potentials of wetland resources in the country. The chapter asserts that the declining environmental resource base of the country is mainly due to anthropogenic influences because wetlands in Nigeria are largely exploited for economic gains and are basically used for subsistence living or for physical development. Statistical data from the government shows that 60 % of Nigerian population depend solely on the natural resource base and

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are engaged in farming, cattle rearing, and fishing. This chapter provides measures which include restoration programs, reduction of further disturbance on wetlands, and legislative and policy formulations for protecting wetlands which are considered appropriate and can contribute greatly in mitigating climate change when properly harnessed as a way forward toward climate change mitigation and adaptation.

Keywords
Wetlands • Climate change • Resource conservation • Adaptive planning • Developing countries, Nigeria

Introduction

Wetlands are the transitional zones between the aquatic and terrestrial environments. Though there is a controversy over its precise definition because of variety in its types and boundary limits, generally it refers to the intermediary zone between permanently wet and permanently dry environments (Barbier et al. 1997). However, during the Ramsar Convention on Wetlands of International Importance, 100 countries adopted an extremely wide approach and defined wetlands as "areas of marsh, fen, peat land or water, whether natural or artificial, permanently and temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters" (Barbier et al. 1997). Mitsch and Gosselink (1993) and Barbier et al. (1997) also described wetlands as "the kidneys of the landscape, because of its role in the hydrological and chemical cycles, functioning as "biological supermarkets" and serving as food webs and supporting rich biodiversity." As an interface or the intermediary between land, sea, groundwater, and atmosphere, wetlands are being regarded as one of the most complex regions on earth (Semeniuk 2012).

In relation to climate change, intact wetlands serve as buffers in the hydrological cycle (Bergkamp and Orlando 1999; Junk et al. 2013) and absolve organic carbon from the atmosphere, neutralizing the effects of atmospheric increase in CO_2 (Junk et al. 2013). In fact, the place of wetlands as an environmental resource is monumental, justifying why research is needed to harness its linkage with climate change, especially in developing countries where coping ability is low.

Unfortunately there is paucity of research results that attempt to establish a nexus between wetlands and climate change. This is corroborated by Erwin (2008), who observed that after examining over 250 articles pertaining to wetlands and climate change in peer-reviewed journals and pertinent texts, there was very little discussion of wetland restoration in the climate change literatures, with only an occasional comment in a very small fraction of the documents. Odjugo (2010) is also of the opinion that though the effects of climate change are more pronounced at the regional levels, most data on it are global in scope. This underscores the need for research initiatives to shed light on wetlands within the frame of climate change adaptation at regional levels using Nigeria as case study.

The study therefore aims at assessing wetland resource services in the context of environmental resource planning for climate change adaptation in Nigeria. The specific objectives are as follows:

- To review the impact of industrialization, urbanization, and subsistence living on wetland resource depletion generally but with specific bias to Nigeria
- To review mitigating and adapting measures in literatures that may be adopted in Nigeria in order to enhance the potentials of wetland resources in the country in the light of climate change

Climate Change and the Environment

The environment operates like a giant single, self-regulating, and self-sustaining organism made up of different components that are intricately interdependent. Each and every component has got a vital function for the sustenance of the system. Any dislocation in one generates multiplier effects on other components; thus climate, for example, has an important influence on any environment and can trigger changes, if altered. Climate changes and the impacts of these changes may affect the environment in diverse ways. Warming, for instance, is capable of forcing species to migrate to areas with lower temperatures and more conducive to their survival. Climate change causes irreversible multiplying effects, manifesting in species adapting, migrating, or perishing which ultimately result to losses in local population (Boer 2012). This development can affect environmental services of a particular environmental resource.

Brundtland report on our common future in 1987 stresses the need for counterbalancing the unmet needs of the current generations with the needs of the future generations (Sneddon et al. 2006). They said most scholars and practitioners have come to accept the Brundtland definition of sustainable development as the most appropriate which hinged on environment and development dilemmas. Mohammad (2011) looks at the environment as the composition of the natural, artificial, physical, chemical, and biological elements that make the existence, transformation, and development of living organisms possible. He went further to say that an environment can only be referred to as sustainable when it possesses the ability to continue to function properly and indefinitely. Environmental sustainability therefore aims at reducing environmental degradation, through the process of stopping or reversing any human activities that lead to it.

The United Nations IPCC report established that human activities, especially those associated with consuming energy from fossil fuel, remain the major source for climate change (IPCC 2007). The panel substantiates the above assertion by reporting that between 1970 and 2004, annual CO_2 emission grew by about 80 % due to human activities from fossil fuel burning. Over the years, humanity has solely depended on fossil energy use because of the huge capital and economic benefits. But the global antecedences attached with this source of energy consumption have proved that it is not sustainable.

In search of the earth's vast seemingly unlimited resources, fossil fuels discovery led to a great transition in our societies which became highly dependent on energy use (Agudelo-Vera et al. 2011). Additionally, industrial societies use three to five times as much energy and materials as did agrarian ones (Krausmann et al. 2008). Available statistics shows that resource consumption by the end of the twentieth century already exceeds the productive capacity of critical biophysical systems on every continent and waste production already breaches the assimilative capacity of many ecosystems at every scale (Rees 1999). To add credence to the above assertion, Vitousek et al. (1997) affirm that we are changing earth more rapidly than we can understand it. The rates at which we generate waste exceed the rate at which the earth can assimilate. Though we have made significant progress in reducing industrial pollution and increasing efficiency, globalization is devastating natural habitats, speeding global warming, and increasing air and water pollution (Mohammad 2011). He went further to establish that the yearning for global nature of trade and business has rendered traditional national environment protection techniques less or ineffective.

The reviewed literatures so far are unanimous in supporting the fact that in climate change and sustainability, the environment occupies a central stage. Hossain et al. (2010) affirm that in sustainability studies, the closest element that should be dealt with in climate change is the environment. An unsustainable situation takes place when natural capital (the sum total of nature's resources) is used up faster than it can be replenished. Sustainability requires that human activity only uses nature's resources at a rate at which they can be replenished naturally. Natural vegetation, green spaces, wetlands, waterfronts, etc., can be affected by urbanization and development.

The key manifestations of environmental change are global warming and climate change. In fact, global warming is considered to be one of the most stressing issues that are currently facing humanity (Mezher 2011). However, the Intergovernmental Panel on Climate Change (IPCC) assessment in 2001 has reported that global warming and climate change are receiving a great deal of attention by governments, businesses, consumers, and the mass media due to its publicized impact on human society, biodiversity, water supply, infrastructure, and desertification (Santos 2011). This is in agreement with the European Commission 2005 report on winning the battle against global warming, who also affirmed that there is general awareness in tackling the problem of greenhouse gases (GHG) emission in the light of its damaging effects on the global environment, economy, and international security (Minoia et al. 2009). But this increasing awareness of the impact of GHG and climate change on the environment is still low in the developing countries compared to that in the developed countries. There is general lack of awareness of the role of the natural environment in mitigating climate change in the developing countries. This again underscores the need for research initiatives to shed light on the role of the wetlands as component part of the environment in mitigating climate change at regional levels using Nigeria as case study.

Wetlands and Climate Change

Statistics has shown that 6 % of the land area of the world is occupied by wetlands (Acreman et al. 2007; Erwin 2008). This contains approximately 12 % of the global carbon cycle (Erwin 2008). Earlier statistics however ascribed greater value indicating that nearly 10 % of the earth's surface is wetlands, of which 2 % are lakes, 30 % bogs, 26 % fens, 20 % swamps, and 15 % floodplains (Bergkamp and Orlando 1999). Wetlands are significant carbon stores, and so the role of their conservation also needs to be considered in the development of climate change mitigation strategies. This is in line with what Bergkamp and Orlando (1999) see as the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) which is to reduce GHG emissions.

Wetlands represent a significant storage reservoir of carbon in the global carbon cycle. Statistics shows that of the total storage of carbon in the earth's soils (1,400–2,300 Pg, where 1 Pg = 1,015 g), about 20–30 % is stored in wetlands, much as peat in wetland soils, and that 0.08 Pg/year is stored as peat in wetlands, a small percent of the 6.3 Pg/year that are produced by humans (Cudmore 2011). He also asserts that disturbance of peat deposits can influence global carbon budgets, combustion, and oxidation of peat deposits, and drainage of wetlands also can release carbon back into atmosphere (could be 45–89 % of the carbon being sequestered by wetlands).

Over the years, however, there has been a remarkable loss of wetlands globally though there are no statistics to support this assertion (Barbier et al. 1997). They however reported significant loss in some countries such as the United States put at 87 ha that is 54 % of its original wetlands, Portugal 70 %, and various degrees of loss in European countries. Factors responsible for natural change on the wetlands include issues such as drought, sea-level rise, and infilling with sediment or organic material. Anthropogenic activities on the other hand, such as subsistence agricultural activities, constructions, developments, etc., are human-induced factors that have affected the wetlands over the years. As a temporary feature of the landscape, natural or human phenomenon can introduce change to the fragile landscape, and without some precaution over its usage, it might eventually disappear with time.

Climate change is perhaps the greatest challenge facing wetland management. And wetlands are perhaps the most susceptible to climate change in the aquatic ecosystem. Shallow wetlands that are dependent on precipitation will be the most vulnerable to drying, warming, and changes in water quality. Intermittent and perennial streams, vernal pools, and coastal wetlands and marshes will also be particularly vulnerable to projected changes in temperature, precipitation, and sea-level rise. Wetlands that depend on precipitation for their source of water according to Winter (2000) are the most vulnerable to changes in climate.

The features of the wetlands in developed economy are slightly different from that of the developing countries. Kulkarni and Ramanchadra (2006) established that the environmental challenges confronting the developing countries are considerably different from those facing the industrialized economies. Their assessment shows that in the developing economies, the rural population depends directly in exploiting the natural resources for fishing, rearing livestock, agricultural, fuel, etc., to meet their subsistence needs and gain income. This has escalated land use change in the natural environment causing habitat disappearance and results to loss of the ecological resources and the functions disrupted or loss culminating in climate change.

Although African countries are exonerated from being major contributors to GHG emissions, as the continent's contribution is relatively low compared to other continents, unfortunately climate change does not know regional boundaries and the region is more vulnerable. In recent years, some countries in Africa such as Ethiopia, Eritrea, Botswana, Zimbabwe, Mozambique, South Africa, and Sudan are experiencing increase in severe droughts as a result of climate change (Spence 2005). Increased dependence on firewood has aggravated forest depletion in most African countries. And accelerated forest depletion according to Alaci and Ato (2012) can alter the microclimatic scenario of an area. Some of the forests depleted are actually wetland forests, apart from the fact that what happened to the forests is a bigger picture of what happens to other components of the ecosystem, wetlands inclusive.

Regional evidence shows that some tropical rainforests in western Africa have become drier since 1960 (Malhi and Wright 2004). This according to Velarde et al. (2005) is an indication that shifts in ecosystems or species habitats in Africa due to climate change are expected and are happening already. The continent is most vulnerable to climate change because most African governments may not have the coping abilities to actively react to climate change and global warming (IPCC 2007). Odjugo (2010) also upheld the above assertion, arguing that even though climate change and its impacts are global, the developing countries will experience more of its biting effects most especially in Africa because coping capabilities are low, coupled with the fact that the region is the least equipped to mitigate climate change impacts (Velarde et al. 2005). And more often in Africa, issues of climate change are neither incorporated in policy development matters nor invested in decision making that mitigates it (UNDP 2006).

According to Hossain et al. (2010), striking a balance between climate change and development is essential for identification and implementation of wholesome approaches that will bring more and more management aspects into fore across different sectors in an efficient way. This they said becomes the bedrock of our achievement in development or managing problems, in a sustainable and advanced manner. Hjorth and Bagheri (2006) have however argued that "managing the future is a 'wicked' problem, meaning that it has no definitive formulation and no conclusively 'best' solutions and furthermore, that the problem is constantly shifting."

Wetland Resource Depletion and Climate Change in Nigeria

The landscape of Nigeria is dotted with wetland resources that spread across the northern and southern regions of the country (Ajibola et al. 2011). The wetlands in the country are categorized into two, the freshwater floodplain (FF) wetlands and the saline coastal mangrove swamp (MS) wetlands (Ajibola et al. 2011). *FF* wetland occupies an area of 9,000 km^2 in the coastal states of Akwa Ibom, Cross Rivers, Delta, Edo, Lagos, Ondo, and Rivers (Agbi et al. 1995), while the MS wetland occupies an area of 858 km^2 located in states such as Rivers, Cross Rivers, Imo, and parts of Edo and Lagos (Eregha and Irughe 2009). However, these are not the only locations where wetlands are found in the country as vast wetlands also stretch along the fronts of river Niger and Benue, the two major rivers in the country. Large quantities of wetlands are found therefore in states such as Kogi, Benue, Niger, Taraba, etc., where these rivers and their tributaries navigate.

While the wetlands in the riparian rural communities in the country are being used mainly for farming as the local populations depend on it for their livelihoods, the ones in the urban and suburban communities are being heavily encroached upon by anthropogenic activities such as industrialization, urbanization, recreation, and developments. These encroachments have also been confirmed by the Federal Government of Nigeria who reported that the proportion of land covered by forest has been reducing by 0.28 % on the average in the country (Federal Government of Nigeria 2008). Alaci et al. (2011) and Kodiwo et al. (2012) confirmed that the declining environmental resource base of the country is due mainly to anthropogenic influences. This declining environmental resource includes the wetlands.

Available statistics have shown that the 140 million population in the country is impacting on the country’s land area of 923,000 km^2 through various physical environmental activities (Gbadegesin et al. 2011). In addition they established that 60 % of this population depend solely on the natural resource base of the country and are engaged in farming, cattle rearing, and fishing while the informal sector still largely controls the economic activities in the urban areas and that the wetlands in the country are basically used for subsistence living or for physical development especially in the semi-urban and urban areas. These activities especially physical development are causing a reduction in the wetland resource base of the nation. This is because physical development has the tendency of changing the entire ecosystem of the wetlands. If the human impact on the wetlands in the country continues in this manner, it will reduce the hydrological and atmospheric carbon reduction capacity of the nation’s wetlands. Unfortunately activities on the wetlands are not regulated, although the country has planning authority that is vested with such power. Most of the wetlands in the urban areas are not delineated as planned areas; hence, activities on it are not controlled and the public opinion formed about wetlands is that of free for all properties.

The effect of climate change that has caught up with Nigeria culminated in the flood event of 2012, reckon to be the worst disaster in the history of the country. Lives were lost, thousands of people were displaced, and properties worth millions of dollars were lost. The riparian communities were badly affected, and even communities that were relatively distanced away from the rivers were amazingly taken over by the flood. The destructions that were caused by this flood were monumental, and for many years to come, many people will still live with shock. The wetland floodplains were believed to have played a vital role in absorbing the excess water, without which probably the magnitude of the disaster would have been more. Statistical values have also indicated that rainfall in recent time has consistently decreased for decades in the Sudano-Sahelian Region of Nigeria, reflecting in significant changes in the climate in the form of desertification (Olatunde and Alaci 2012). In crop yields, for instance, Adejuwon (2006) predicted that even though there will be increase in some areas in the country toward the early part of the twenty-first century, toward the end, however, there will be a decrease. Rise in temperature beyond the coping capability of the crops he maintained could cause the decrease in yields. Some parts of the country are experiencing this already.

The Way Forward in Management of Wetland Resource in Nigeria

Alwi et al. (2011) are of the opinion that in order to achieve sustainable development, conservation, appropriate planning, and management of natural resources remain the key elements to be considered. Planning according to Taylor (2010) should not only be concerned with planning the overall physical environment but should encompass the planning and management of the environment in all its aspects including especially the natural environment with its delicate ecology and pattern of habitats. In the forest resource conflict, for instance, Campbell (1996) reported that industrialists must curb their profits increasing tendency to boost timber yields, so as to ensure that enough of the forest remains to "reproduce" itself. He called this practice "sustainable yield," though timber companies and environmentalists disagree about how far the forest can be exploited and still be "sustainable." Although at least this is a sector that has been identified in the environment, methods on how to enhance sustainable practice in the sector can be explored in spite of the debate. This idea can be applied to wetland resource, identifying it as an important sector of the environment in mitigating climate change and controlling its uses as we advance on the debate on the best possible ways in sustaining its usage. Unfortunately these suggested methodologies are nonexistent in Nigeria; if conservation does occur, they are incidental unless were adopted as open space in urban master plan. Destruction of wetlands in attempt for new buildings in urban areas and farming activities is rampant in many rural communities across Nigeria. Deliberate policy guideline on wetland protection is absent, while games harvested from such areas remain choice delicacy among Nigerians.

To ensure that sustainability is achieved both at the global and regional levels, a reduction in resource consumption is particularly relevant. Nature is the common heritage of mankind; to preserve this heritage, mankind must learn the culture of conservation. In spite of the designation of few wetlands as Ramsar sites, Gopal (2013) argues that there are very weak or nonexistent policies concerning wetland conservation globally. This is certainly more obvious in the developing countries, Nigeria inclusive. The idea that has been promoted by both Taylor (2010) and Alwi et al. (2011) as discussed previously remains ideal for the management of wetlands in Nigeria. The frontiers of planning rules and regulations should go beyond the built environment to the fragile component of the landscape like the wetlands since they play a vital role in absorbing excess CO_2 from the atmosphere. Previous studies on wetlands in Nigeria have not adequately related it to climate change and formulation of relevant planning policy that enhance wetland protection.

Although many people are aware that one of the problems facing mankind today is climate change and sustainability, only very few are however conscious of engaging in behaviors that will mitigate climate change (Gifford 2011). Since it is no longer possible to avoid some degree of global warming and climate change, even if efforts to reduce GHG emissions are successful, studies are therefore needed on how to overcome or minimize impact of climate change especially in a developing country like Nigeria. There are two possible strategies, one is mitigation and the other is adaptation. While mitigation is the effort put forth in reducing the accumulation of GHG in the atmosphere, adaptation is all about adjusting to the impact of global warming (Kwok and Rajkovich 2010). This implies that mitigation is attempting to prevent global warming from happening; adaptation is looking for better ways to live with it since it has happened. Adger et al. (2003) look at adaptation to climate change as the adjustment of a system in moderating the impact of climate change by taking advantages of new opportunities or deciding on the best way to cope with the consequences. The IPCC (2007) report said it is the natural or human system adjustment in response to climate stimuli or their effects. Burley et al. (2012) sum it up as exploiting opportunities or moderating harm.

Literature concurs that for adaptation to climate change to be effective, it has to be at the individual finer level of scale such as nature reserve, parks, or watersheds (Mawdsley et al. 2009). Wetland therefore is considered appropriate as one of the finer scales in the environment that can contribute greatly in mitigating climate change when properly harnessed. Wetland users in Nigeria need to seek for fresh environmentally friendly resource utilization of the wetlands by seizing the opportunities that climate change offers or devising conservative measures to cope with its impacts.

There are diverse ways or methods for wetland adaptation to climate change from the literature. But the method to adapt should be a function of prevailing situation because the scope and the nature of the challenge are not the same. According to Mawdsley et al. (2009), no one particular method or strategy is considered optimal over others; hence, the circumstances under review determine which one is more or less appropriate. Others have also concurred asserting that an action that is acceptable by one group, government, or individual may not be acceptable for another and that success should be defined by scale of implementation and the criteria used for evaluation (Adger et al. 2005). Adaptation to climate change however should be ultimately a collective responsibility of the society, while its application may involve individuals, groups, civil society, or the government (Tompkins and Adger 2004; Adger et al. 2005).

Rebecca et al. (2012) have put forward several strategies in coping with climate change. Their strategies are summed up in promoting system *resistance* and *resilience*. The ability to withstand environmental change is what they referred to as resistance, while bouncing back or absorbing environmental change is resilience.

However, some broad-based practical strategies have been recommended in the literatures on the use of wetland resource as mitigating or adapting measures to climate change. Since the assessment of the wetland resource in Nigeria shows lack of regulatory rules on its usage and the country is already experiencing climate change, there is a need to look for ways of reducing or minimizing human impacts on the wetlands.

Among the volumes of the recommended strategies in the literatures, we put forward three for adoption in Nigeria. These strategies are recommended against the background that they are simple to practice as some have been applied in other developing countries like Nigeria. Some of the strategies are not particularly on the wetlands but may be applied. These strategies include issues such as the restoration of wetlands or the entire ecosystem (Erwin 2008; Lawler 2009; Mawdsley et al. 2009), reduction of further disturbance (Erwin 2008; Lawler 2009; Harvey et al. 2012), and legislative and policy formulations (Hartig et al. 1997). The views and principles surrounding these strategies are discussed in the following subsections accordingly.

Wetland Restoration

Erwin (2008) suggested that wetland restoration programs should form part of the restoration projects and policy makers should strategically inculcate wetland restoration into the overall plan as climate change mitigation and adaptation measures. Boer (2012) concurs and is of the views that when wetlands, streams, or riparian zones are restored, it provides buffers that cushion the effects of climate change on the species and the ecosystem at large. Acreman et al. (2007) on the other hand recognize wetland water management as key element in wetland restoration efforts, because hydrology plays a crucial role in wetland maintenance. Created and restored wetlands have the potential to play an important role in carbon sequestration. Rates of 180–190 g C/m^2/year have been reported for created wetlands in Ohio (Cudmore 2011).

Reduction of Further Disturbance on Wetlands

The diminishing ability of the wetlands to respond to climate change among other factors is the issue of intensive use by man in quest for industrialization or subsistence living. Management strategy requires further minimal use of the wetlands. Prevention or reduction of additional stress should be avoided so as to allow the wetlands' response to climate change (Erwin 2008). This stress includes issues such as maintaining hydrology, reducing pollution, controlling exotic vegetation, and protecting wetland biological diversity and integrity. Lawler (2009) on the other hand has confirmed that removal or reduction in the existing environmental stresses and threats to population or species does enhance resilience to climate change in some cases.

Legislative and Policies Formulations for Protecting Wetlands

Hartig et al.'s (1997) review on Eastern Europe's wetlands advanced that the formulation of policies that will protect wetlands will be of assistance to countries that are vulnerable to climate change. They suggested precautionary management measures for sustainable wetland utilization such as establishing buffer zone, advocating for sustainable uses of wetlands, and recapturing of farmed or mined wetland areas. These measures are conspicuously absent in Nigeria as established previously.

In the light of the function of wetlands in mitigating climate change as carbon sink, there is a need for policy makers to establish wetland buffer zones, reclaim wetlands that have been lost to other economic activities, and encourage sustainable use of the wetlands, among others. This will entail that wetland legislative and regulatory laws have to be enacted and enforced. Individuals are not autonomous in decision making in respect to adaptation. There ought to be guiding rules by government institutions that should cover areas such as regulatory structures, property rights and social norms, and associated rules in use (Adger et al. 2005).

Adapting measures that will mitigate climate change has to be multidimensional and not necessary restricted to one component of the environment. Others have also suggested that a multilevel governance approach, by cooperative actions at the different institutional scales, is a step in the right direction toward mitigating and adapting to climate change (Minoia et al. 2009). This they said can be accomplished through delegations of functions from the central government to regional and local governments, so as to support and contribute to the overall effort in reducing GHG through their own policies and actions. GHG emissions can be reduced by the regional or local governments through spatial planning and transport policy, energy-efficient construction, and the renovation of energy-wasting buildings (Minoia et al. 2009) and by promoting renewable sources of energy (Minoia et al. 2009; Mezher 2011). In Nigeria as of the moment, there are no relation between all levels of governance in respect to wetland protection and no regulatory laws, exposing the wetlands to untamed usage. The wetlands for now are synonymous to being an open access. Promulgating laws to protect the wetlands is eminent.

However, policy makers are not only expected to enact laws but ensure that they are enforced. An assessment of the study by Sonak et al. (2011) on Goa wetlands shows that although there were existing legislative rules put in place to protect this particular wetland, implementation was marred by corrupt practices of the officials, leading to policy distortions and weak implementation. Unfortunately, corruption for now is a serious epidemic problem confronting governance in Nigeria at all spheres. Nigerian government therefore has to ensure that laws for protecting the wetlands are not only formulated but implemented. Adopting the above-recommended strategies will not only enhance wetland ecosystem but ensure that it continues to provide its ecological services amidst changing climate.

Conclusions

The management of the natural resources, the natural environment, and the wetlands in particular is therefore crucial to sustainability and climate change mitigation in Nigeria, Africa, and the world at large. Local authorities need to pay attention to the stocks of natural, social, and cultural capital in their communities, since all of these can decline over time in the absence of private and public investment to maintain or increase their value (Saunders and Dalziel 2010). In accordance with Ramsar recommendation, the government and the planning authority in Nigeria can identify wetlands that are of ecological importance and designate their sites for protection at the local levels. This according to Minoia et al. (2009) can be accomplished by the local planners and institutions through evaluation of all the sectors so as to identify the best sectors that needed to be regulated locally and by which planning tool. Research gap exists in information dissemination among researchers, policy makers, and wetland users in respect to human impacts on the wetlands and the resultant effects on global warming and climate change especially in the developing countries. Research findings on wetlands and climate change for now are within the corridors of academicians and researchers. Further studies may therefore focus on reviewing studies on dissemination of research findings on wetlands and climate among the various stakeholders in Nigeria and other developing countries. Erwin (2008) established the need for educating both the public and private sectors so that wetland protection, management, and restoration can be redefined by all in view of climate change.

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Understanding and Managing Climate Change Risks and Adaptation Opportunities in a Business Context

Ioannis Chrysostomidis and Lisa Constable

Contents

Abstract

Climate change poses complex challenges for business not only because of uncertainty associated with the timing and magnitude of projected changes but also because of the interconnectedness between risks and impacts in the modern globalized economy. Drawing on the practical experience with forward-thinking companies in the extractives, chemicals, power, transport, and agriculture sectors, this chapter introduces the concept of systems thinking for managing climate risk and developing adaptation strategies and presents four key steps that businesses can take to (1) understand climate context, (2) assess climate

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risks and opportunities, (3) develop a business case for managing climate risk and build resilience throughout their value chain, and (4) create a strategy to provide direction and ensure integration within the business. It also presents practical examples of how businesses are addressing these challenges through case studies in a number of business sectors. By providing a means for companies to "see the wood for the trees," the practical actions required to manage climate risk are demystified, and business leaders are provided with tools to help ensure that their companies are proactive in understanding and managing climate risk and adaptation.

Keywords
Climate risk and adaptation • Resilience • Risk management • Systems thinking • Scenario planning and strategy

Introduction

The Earth's atmosphere has always contained greenhouse gases (GHGs), and their ability to trap heat within the atmosphere is responsible for the ambient temperatures under which communities and economies have developed (IPCC 2013). The concentration of GHGs in the atmosphere has always varied naturally as a result of complex cause and effect feedback cycles within the long-term carbon cycle, which is affected by photosynthesis and respiration of plants, weathering of silicates and organic carbon, ocean circulation, and precipitation (IPCC 2013).

Temperature and atmospheric GHGs are intricately linked in this system, and the Earth has already experienced a modest increase in global average temperature of 0.8 °C since preindustrial times (World Bank 2012). Changing mean surface temperatures affect atmospheric circulation, and even small variations in average conditions can have a big influence on weather extremes such as droughts, floods, and hurricanes, as have been witnessed around the world over the last decade (IPCC 2012).

As climate-related risk events become more frequent and climate change continues to modify operating environments, risks and opportunities will grow in importance for business.

Given the complexities of the natural system, the impact of climate change is far reaching and has numerous interconnections with other risks and facets of society as illustrated in Fig. 1 which shows risks linked to failure of climate change adaptation.

A system is a set of interdependent components that through their relationships with each other form a complex integrated whole. Changes in any of the systems components illustrated in Fig. 1 can have domino effect implications for any of the others given the feedbacks integrated within the system. For example, failure of climate change adaptation can exacerbate both the likelihood and impact of other risks, and the bolder the line, the stronger the correlation. Global governance failure, water shortage crises, water supply crises, persistent extreme weather, and

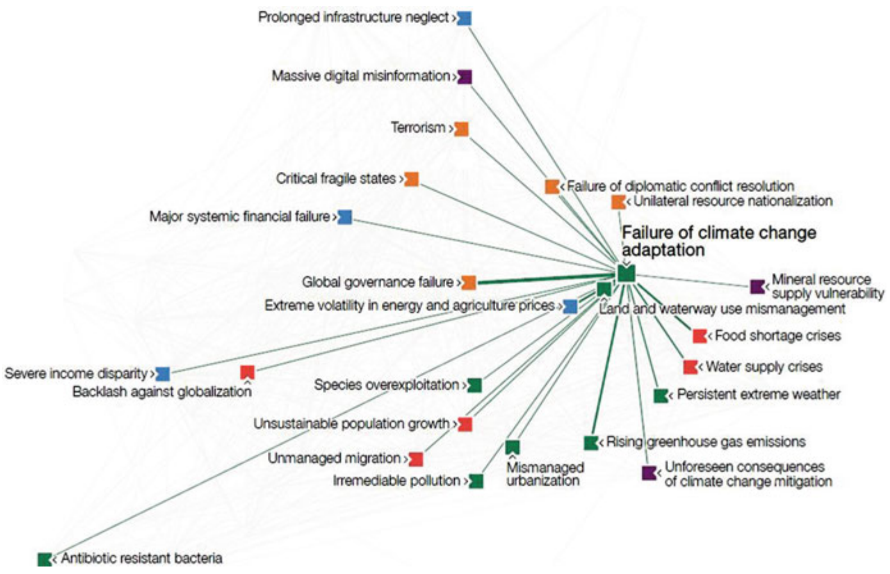

Fig. 1 Systems diagram for risks associated with "failure of climate change adaptation" (WEF 2013)

rising greenhouse gas emissions are the categories most correlated with failing to adapt to climate change (WEF 2013).

A web of interdependencies can give rise to additional risks that are connected within the risk system and once manifested can have knock-on implications within business and societal systems.

Risk Interconnectedness and Domino Effects

Take, for example, the agriculture sector which is being impacted by persistent extreme weather such us flooding and droughts. A failure to adapt to such events could cause food shortage and water supply crises and subsequently increase the risk for other connected events such as unmanaged migration (e.g., millions of people in East Africa as the region suffers its worst drought in half a century) (BBC 2011). It can also cause governance failure and nondiplomatic conflict resolution (e.g., the Darfur conflict in Sudan was fueled by decades of persistent drought) (Humanitarian Exchange Magazine 2008). When risk interconnectedness is "unpacked," it becomes evident that there is a lot more at stake than just what is obvious.

Furthermore, like the complex system which creates the risk, modern business is globalized, interconnected, and interdependent, both vertically (throughout the value chain) and horizontally (companies among same sector), and this can further complicate profiling business risk for a company. A good example is the 2011 floods in Thailand which caused a number of computer hard disk (HD) drive manufacturers to shut down. Aside from businesses like Western Digital and other HD manufacturers who were directly impacted by flooding, the domino effects of this incident resulted in a global shortage of HD drives impacting the sector's *customers* (the computer manufacturer Hewlett Packard lost approximately US$2 billion) and *employees* (NEC slashed 10,000 jobs worldwide amid performance fears of its platform business that was hit due to flooding), all the way down to *consumer* and *business* level (adding $5–10 to the cost of each hard drive and ultimately computers) (Associated Press 2012).

One way to analyze these interconnected risks and opportunities is with *systems thinking*. A systems thinking is a "dynamic thinking" approach which promotes the understanding of risks and their boundaries within a system, how they influence one another, and what patterns emerge and manifest within a value-generating system. It encourages one to "push back" from events and points in time to see the pattern of which they are a part of. The implication is that one will be capable of dealing with a dynamic, rather than only a static, view of reality and thus manage risks better (Barry Richmond 2004).

These interconnected risks and systems are usually beyond a company's capacity to influence or control, but systems thinking combined with approaches like scenario planning offers management a means to entertain possibilities and attempt to both strengthen resilience and reduce the impact cost where this is needed.

This chapter introduces the concept of using systems thinking in conjunction with traditional risk management methodologies to support adaptation and provides a step-by-step guide to understanding and managing climate risk and adaptation – including discussion on scenario planning and how it can be used in a business context to strengthen resilience.

Overview of Climate Risk

Weather varies around long-term climatic averages with some years experiencing above or below average rainfall/temperature producing one-off extreme events such as flooding, heat waves, drought, cyclones, etc. The frequency and severity of events have traditionally been relatively predictable within critical coping thresholds as illustrated on the left-hand side of Fig. 2.

The critical threshold is the point beyond which the consequences are considered unacceptable to the business. Thresholds may be natural, such as the water level at which a river bursts its banks, or a temperature threshold above which machinery cannot operate effectively, or they may be socially constructed based on risk attitude, such as the 1 in 200-year return period for coastal inundation.

The increase in atmospheric GHG concentrations is causing long-term average climate and weather conditions to change. This means that weather vulnerability could increase as the number of extreme events exceeding the critical coping threshold rises over time, as illustrated on the right-hand side of Fig. 2. Basically, climate change loads the dice in favor of more frequent and/or severe extreme

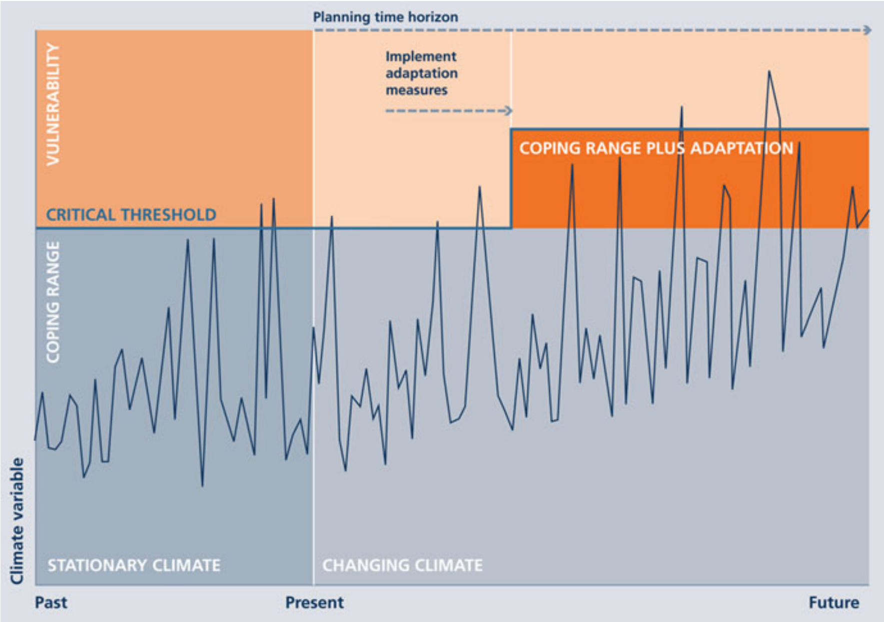

Fig. 2 Climate variability and coping ranges (Willows and Connell 2003)

weather events. Consequently, a critical design threshold (e.g., 200 mm rain in 24 h, 160 km/h wind speed) is expected to be breached more often and/or more severely now, compared to 20 years ago, and in the future compared to now.

The risks and opportunities from long-term climate change are not as easy to identify as those from extreme weather events. There is an anecdote about boiling a frog which is useful in explaining our collective fundamental difficulty in reacting to significant changes that occur gradually. As the explanation goes, if a frog is placed in a pot of boiling water, it will quickly jump out of harm's way. However, if the frog is placed in a pot of water at room temperature and the temperature is slowly turned up over time, the frog will only seek to adjust its own body temperature to match that of the environment, and by the time the temperature becomes deadly, it is too late for the frog to escape. Jumping into boiling water can be compared with experiencing extreme weather events – generally easy to detect and relatively easy to enhance resilience. On the other hand, the impact of incremental changes in temperature are not necessarily easy to identify, and it is important to think about how long-term climate change might affect activities before getting too comfortable in the cooler water and becoming less attuned to the change taking place gradually.

In this context, forward-thinking businesses are beginning to identify their exposure not only to extreme events but also to gradual climate change. They are looking to understand the financial implications, enhance the resilience of their operations, and readjust their core business strategy going forward. Such companies already identify innovative advantage and competitive edge through adopting strategies which provide solutions to real problems posed by climate change, in the same way that digital technology has been the driver for consumer growth in the last decade. For example, companies are already moving to take advantage of significant market opportunities that exist in providing solutions to water scarcity (e.g., desalination, water efficiency, water distribution, manufacture of pipes/pumps, wastewater treatment projects, and irrigation projects) to key industries such as power, steel, paper and pulp, and cement (HSBC 2011).

Traditional risk management techniques can help manage and adapt to the operational risks amplified by the changes in the frequency and severity of extreme weather events.

Long-term climate changes tend to be systemic, i.e., influence many parts of the environmental, business, and societal systems with a wide web of impact connections, and can bring risks and opportunities of a different scale. Resilience to risks or positioning to enhance opportunities can be built by taking a more holistic *systemic* and *scenario planning* approach to managing climate change and enhancing traditional risk management approaches (see Step 2 below).

Managing Extreme Weather

Climate change is transforming primary weather/climatic conditions, which in turn influences the frequency and severity of extreme weather events, resulting in unexpected impacts. Interconnected feedback loops within the broader climate system as well as between the cause and effect illustrated in Fig. 3 could result in numerous difficult-to-predict consequences for business activities, a selection of which are illustrated below.

The feedback loops that exist between events and consequences are important to consider as they can create a web of domino effects between orders of cause and effect with the resultant systemic risks being more complicated to manage than the initial link. *Systemic risk* is a risk that has multiple pressure points and is affecting numerous components within a system. Such risk could potentially influence and impact the entire system, as opposed to risk associated only with any one individual entity, group, or component of a system.

In order to understand the impact of climate change, it is necessary to appreciate both the biophysical impacts of altered weather patterns and the operational, social, and institutional implications of these changes. Climate change impacts are seldom discrete as described in the case study below.

Case Study A mining company operating in water-stressed South America pumps water from a desalination plant at the coast to the mine in the mountains. Changes in precipitation could cause landslides and compromise the integrity of the water pipeline. To secure water supply, the site applies for and secures a temporary

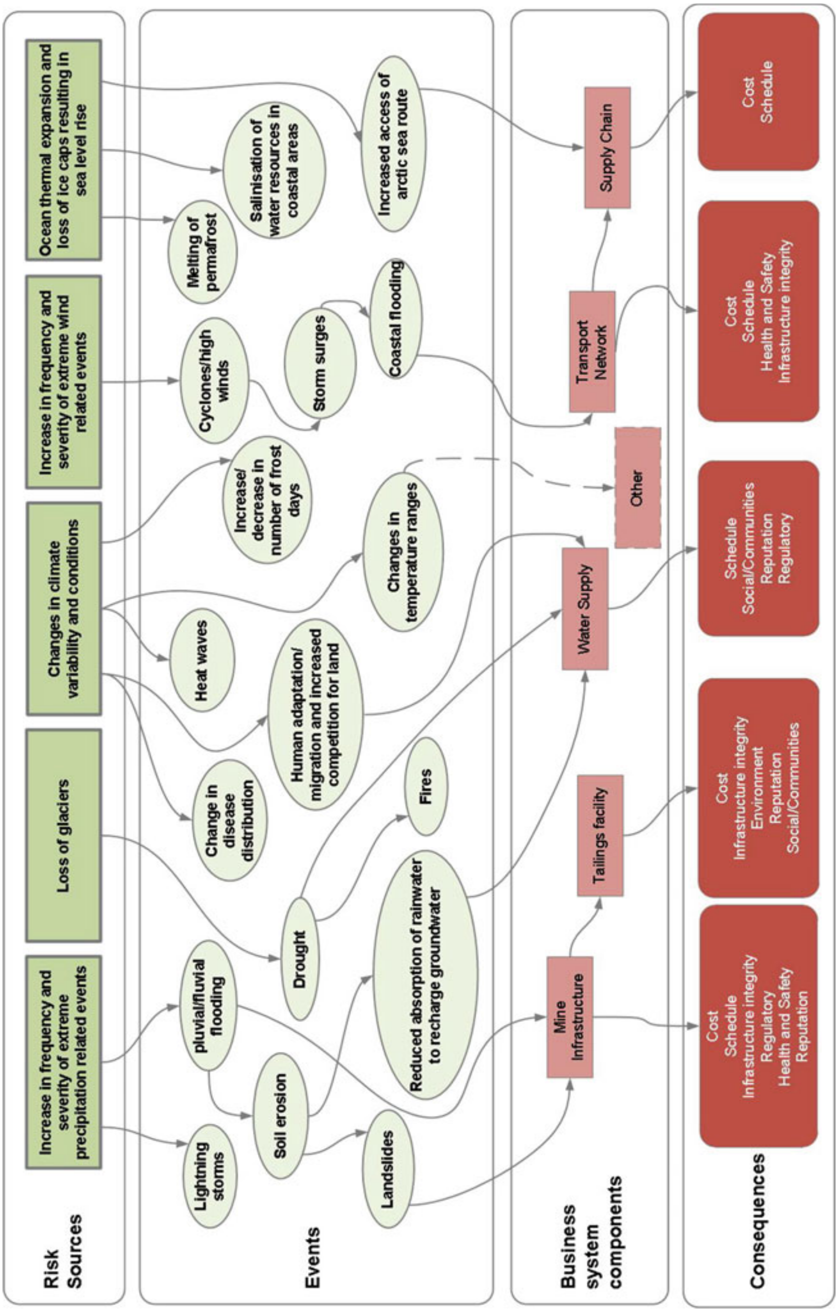

Fig. 3 Climate risk map example for a mining complex

groundwater abstraction license. This source is already under pressure due to historical water stress conditions, and this is exacerbated by reduced groundwater recharge from rainwater due to changing precipitation patterns – the thing causing the problem from the start. Abstraction of groundwater for industrial use at the mine further exacerbates drought in the area and has unintended and unforeseen impacts on local ecosystems and farming activities, erodes local community support, and seriously jeopardizes the project's license to operate.

Business leaders are becoming increasingly more adept at thinking commercially about the system within which they are operating. What this means is framing the systems boundary, identifying the critical interacting elements in the "business system" and how they relate with and affect each other, and keeping the big picture in mind without reducing it down to its component parts in such a way that ignores the interconnectedness. A key aspect to all this is the ability to see relationships between components where once they might have only seen individual parts and to be able to identify the critical relationships that cause the significant positive or negative impacts. It also means being able to look at problem situations and knowing how to resolve them from a variety of points of view and using different *systems* approaches in combination. This approach encourages a kind of creativity to managing a problem.

A certain tolerance to messiness, uncertainty, and ambiguity is needed in order to avoid jumping to solutions too quickly. Spending time in the ambiguity and confusion tends to lead to more elegant, resourceful, and effective responses.

Mapping systems dynamics and identifying and mitigating potential risks early give business leaders the opportunity to refashion their operations, reposition their products and services, and ensure an increasingly sustainable market position.

The remainder of this chapter looks at ways in which climate risk management can be embedded within a systems approach to scenario planning and organizational management aimed at enhancing the resilience and therefore profitability of companies in the face of climate change.

Step-by-Step Guide to Understanding and Managing Climate Change Risks and Opportunities

Understanding the impact of climate change on an organization or site might seem like a daunting task, but focusing the activity in a few simple steps will allow for comprehensive analysis of the business case for undertaking adaptation and the development of a strategy for managing climate risk in the future. The four-step approach summarized in Fig. 4 and discussed in detail in the remainder of this section aims to provide guidance on where to find information and how to interpret it within existing business processes. It draws on the systems approach to ensure that the full range of risks and opportunities are considered and that holistic approaches to managing and leveraging these are identified.

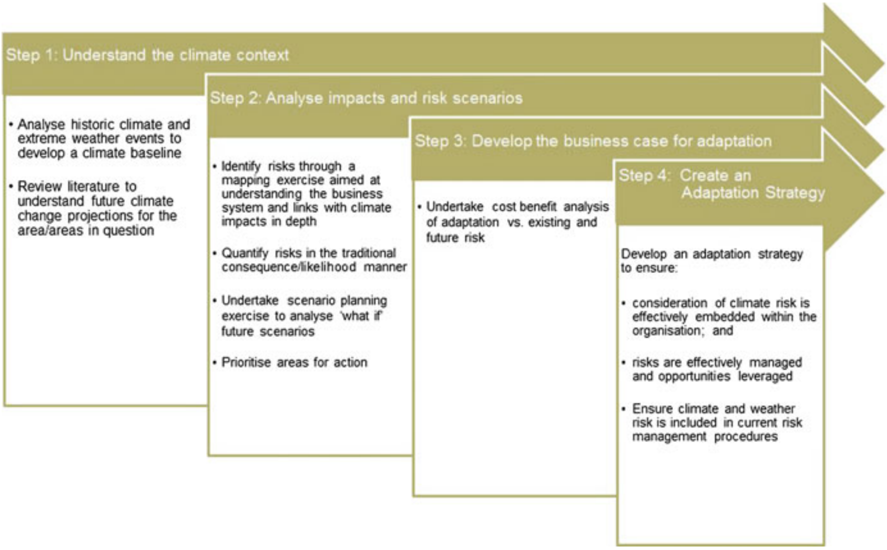

Fig. 4 Overview of step-by-step approach to understanding and managing climate risk and opportunities

Step 1: Understand the Climate Context

The historic climate baseline and projected change in the climate for a project area should be understood so that information on key climate change risks or opportunities can later be identified and ultimately considered in project investment decision making.

Historic Climate Baseline

Information on the climate baseline for an area is important in helping to understand risks associated with current climatic conditions and to provide a reference point from which future climate changes can be assessed as illustrated by the case study below.

Case Study A coal-fired power station in Asia regularly experiences typhoons. Coal storage facilities were originally built to withstand the maximum wind gust speeds experienced at the site in the past 50 years. During typhoons in 2004 and 2005, the domes covering all three storage facilities were torn off resulting in business interruption, reduced efficiency (from wet coal), and high maintenance costs. Analysis of maximum wind speeds in the region around the plant suggests that gusts have reached up to 110 m/s in the past. This figure should form the baseline from which to assess changing typhoon intensity as a result of climate change as it provides an estimate of a possible worst-case scenario in the region.

The following information is useful when compiling the baseline:

- Local weather stations can provide valuable site-specific weather data, including historical temperatures, wind speeds, and precipitation levels. Local environmental/meteorological agencies should be contacted to explore what climate data may be available for an area and how useful it could be in informing the climate baseline.
- National meteorological agencies can provide useful information on "typical" conditions in various regions, such as average temperatures and precipitation levels by month. Information on historical incidences of severe weather events in the region (e.g., floods, droughts, and storms) may also be useful in informing the climate baseline for a site area.
- Global climate datasets (e.g., Climate Research Unit Global Climate Dataset (UAE 2013)) frequently have lower resolution and are therefore less accurate at a site level but can be useful in providing climate data where more local information is lacking.

In addition to establishing an understanding of the physical climatic conditions for the site, information on the social and regulatory climate context for the site should also be gathered.

Climate Change Projections

Having constructed the climate baseline for a site, projections of the estimated change in the regional climate should be analyzed. Climate change projections are typically determined for future scenarios in the middle to the end of the twenty-first century. It is recommended that the climate change horizon selected is in line with the projected lifetime of operations including a period post-closure.

Climate change projections are based on the output of global or regional climate models. These models can be used to obtain climate change projections and data for a particular area. A more textured understanding of projected changes can be achieved through "downscaling" with modeling at regional, provincial, or catchment level. It should be noted that there will be uncertainty in the climate change projections for all climate variables and this needs to be considered in the development of impact scenarios as discussed in Step 2.

Understanding the potential impact to project/operations involves analysis of the climate baseline and projections for the site area in order to understand how current conditions may change in the future. Some example interpretations of climate change projections are provided below:

- Projected increases in precipitation intensity and winter rainfall could mean that in future there is increased flood risk in localized sites in the region that are vulnerable to flooding, for example, sites located at the base of a hill, near to a body of water, or in a relatively flat area with poor drainage capacities.
- Projected increases in average and maximum temperatures could mean that there is increased risk of heat wave events during the hot summer months.

- Projected intensification of tropical storm and cyclone events for a site area located in a tropical cyclone zone could mean that there is increased risk of damage and disruption from storm events in the future.

Step 2: Analyze Impacts and Risk Scenarios

Having understood the impact of climatic events in the past and assessed potential climate change projections in a region of interest, the assessment can now focus on analyzing the impacts and risk scenarios facing the organization.

Risk Mapping

A useful starting point is to generate a *value generation map*. Value generation is the process by which a business creates value from a commodity, e.g., mining activities which create concentrate from ore in the ground; refining raw fossil fuels into other fuels, plastics, etc; and converting crops into luxury products. The value generation process involves a series of inputs, outputs, and associated activities. Figure 5 presents a simple value generation map for a mine and includes the critical *inputs* that need to be sourced (e.g., people, technology, materials, energy, and water) and the *value eroders* associated with mining activities (e.g., mineral and non-mineral waste, landscape/ecosystem alteration, air/GHG emissions, people displacement, etc.). Then follows an identification of a number of *value enablers* and *value protectors* that have to be in place to ensure the uninterrupted flow of inputs (water supply, energy power supply, transport network, etc.) and management of value erosion (e.g., tailing facility, waste rock facility, etc.). It is worth noting that this map is not linear and there are also connections between enablers and connections themselves, e.g., failure of the tailing facility (i.e., a value protector) can jeopardize the presence of a series of value enablers (e.g., community support, license to operate, etc.). Developing such a map will allow for better identification of the critical business components and how they are connected and where the climate risk assessment should focus from an impacts perspective.

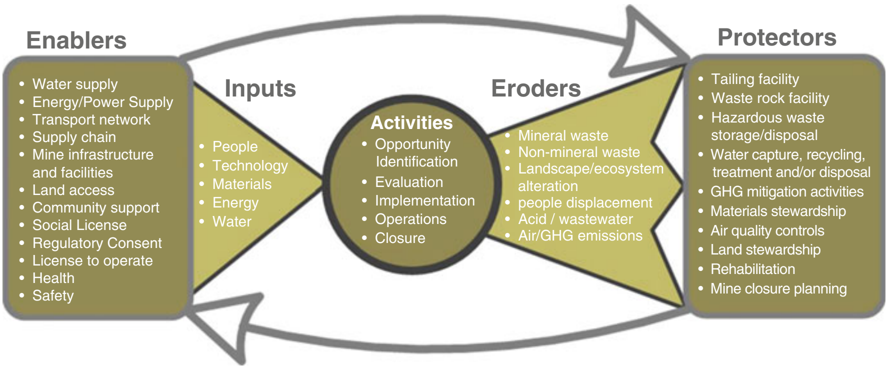

Fig. 5 Mining value generation map

Following the identification of value enablers and protectors, the next task is to develop a *climate risk map* in order to obtain a complete overview of the situation including systemic interconnections. This includes identifying the possible risk sources and associated events, the influence these may have to different components within a business value-generating system, and the likely consequences should the risk materialize. The way climate change interacts with a business system represents complex systems dynamics that would be influenced by long-term climate change (i.e., risk sources) but manifested in distinct events (e.g., risk of flooding, risk of landslides, etc.). A simplified example of this focused only on flooding at a mining complex, and how this might impact value generation protectors and enablers is illustrated in Fig. 6.

Quantifying Risk Using Traditional Methods

Quantitative methods have been developed to help respond to the need to understand and assess the potential impact of extreme weather events and the associated risks. Quantitative assessments focus on assessing risks that arise from an increasing frequency and severity of extreme weather events using likelihood/consequence based on traditional risk management approaches.

Insurance records, underwriters' reports, insurer's catastrophe modeling and operating data, and historical incidence databases along with climate change projections and other data sources can be used in conjunction with sensitivity analysis to quantify relative changes in risk. The purpose is to support judgments about typical business interruption delays or proportion of assets damaged to take account of the specific vulnerability to a given threat. For example, a transport route that has experienced damage or closure due to flooding in the past would be considered highly vulnerable. The key calculation traditionally combines event frequency, severity, financial consequence, and projected climate change to determine the level of risk to a company's operations and assets.

This standard risk assessment process typically involves two steps, with the baseline or existing risk assessed in the first stage as illustrated in Fig. 7.

Once the baseline risk has been identified, frequency and severity parameters can be modified based on values that come either from climate change projections (depending on level of confidence), stress testing or scenario planning (see below), or a combination of these as illustrated in Fig. 8.

Likely impacts to an asset should be considered for the life of the facility including a period following closure and should typically cover the assets, activities, and operations, including the supply chain, as illustrated in the following case studies:

Case Studies *Increased precipitation, flood, and landslide risk* – A regional transport infrastructure development project in Africa looks to ensure that upgrade and new infrastructure projects are resilient to changing risk profiles in 50–100 years by designing bridges, roads, ports, and railways to higher flooding, rainfall, and land stability specifications than has been the case in the past.

More frequent or severe heat wave events – A gas-fired power station in India currently experiences 1.5–3.5 % reduction in generating capacity per year as a result of for each day exceeding 28 °C. As mean temperature in the area is projected

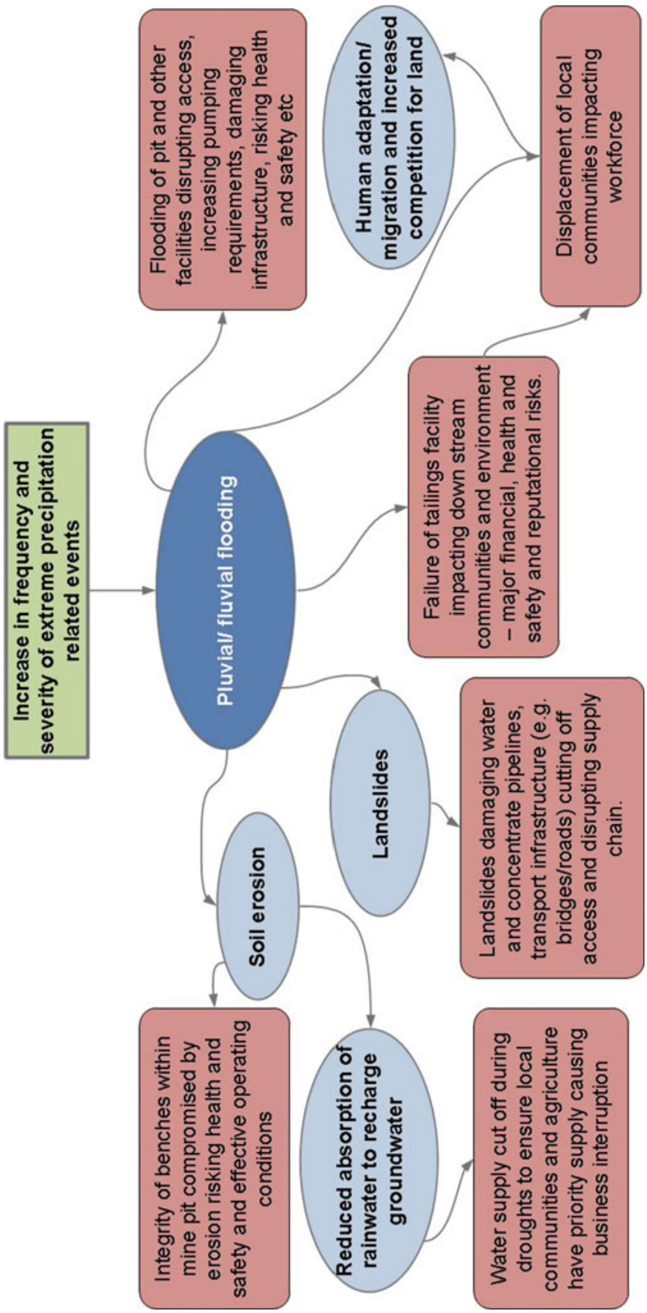

Fig. 6 Flooding risk map for a mining complex

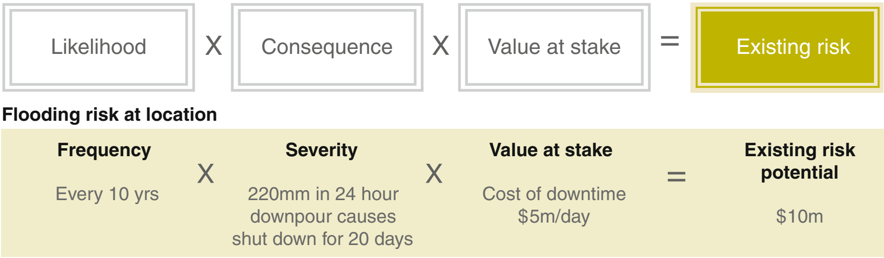

Fig. 7 Assessing baseline (existing) risk (ERM 2012)

Fig. 8 Estimating future risk (ERM 2012)

to increase by 3 °C, the number of days exceeding 28 °C will increase further reducing the generating capacity of the plant. Given that power demand rises during heat waves through increased use of air conditioners, this reduction could risk security of supply and contribute to heat stress in employees and the local population.

More frequent or intense cyclone events – A chemical manufacturing company's facilities in Mozambique and the USA are shut down during cyclones to ensure employee safety and limit the number of people on site in the event that access is restricted. Their facilities in South Africa have experienced supply chain disruption with heavy seas, caused by cyclone/storm activity, preventing feed-stock import.

Changing temperature and precipitation patterns – Recognizing the impact of climate change on biodiversity and ecosystems, a mining company considers how natural vegetation might change in the future in order to ensure that rehabilitation activities and the mine closure plan reflect the potential climate once operations cease in 50 years' time and that sustainable measures are recommended rather than trying to replicate an environment which no longer occurs in the area.

Enhancing Traditional Risk Management Approaches

Risk Amplification

Businesses are constantly undertaking investments on the basis of a set of technical or nontechnical risks that in most cases are considered static and unrelated. For example, social issues in relation to water resources and resettlement may have been identified and are being addressed, but if the effects of climate change are not taken into account, then the sustainability of the solution is not secure and water and social issues may be amplified in the future. Business leaders would be well advised to further consider how climate change and other critical factors might amplify seemingly unrelated risks and their relationships among them or create new opportunities.

Some questions which should be considered during decision-making processes include:

- To what extent will climate change amplify items in the existing risk register?
- How would changes in one set of risks affect other risks in the register or create new risks?
- Proposed resettlement, closure, or environmental/biodiversity management plans will perform differently 30 years from now. How can these plans be modified, and/or what measures can be put in place now to ensure effective performance within and outside the organization in the future?
- How can an operation's supply chain and logistics strategy take advantage of the new transport routes (e.g., arctic passage) or future changes in market conditions?

Stress Testing

In addition to using climate projections, stress testing can be a useful exercise where a "what-if analysis" can be used to assess the resilience of a given operation to hypothetical external shocks. This could assess, for example, what might happen to a project's risk register if future climatic extremes are being underestimated by 20 %. This process can help with uncertainty associated with climate change projections and identify vulnerabilities and opportunities for quick wins.

Scenario Planning

Scenario planning recognizes that many factors may combine in complex ways to create future scenario stories both plausible and surprising. Scenarios take into account climate change and how it might interact with other risk drivers that are not necessarily solely climate-related. For example, scenarios should be developed for social, political, economic, and regulatory issues relating to water scarcity, temperature rise, etc.

The types of indicators used to develop scenarios fall into two broad categories:

1. Those which are relatively *certain* such as demographics, water users in the area, etc.
2. Those which are relatively *uncertain* such as the exact timing and impacts of changes in precipitation, the magnitude of a landslide, etc.

By collecting information about trends and attempting to spot a pattern, trend analysis can be used to inform a series of possible future events. By combining certainty with uncertainty, business leaders can start forming future scenarios beyond the obvious asset impacts. The value of scenarios is that they help companies understand how the various components of their complex and interconnected risk landscape are changed if one or more parameters change. This approach can be used for decisions at a project level, e.g., optimizing economic performance of a manufacturing facility, and for strategic planning at a corporate level as illustrated in the case study below.

Case Study A global agribusiness company informed their medium-/long-term global expansion strategy by using scenario planning to build an understanding of future water scarcity issues and how these will be influenced by climate change among other risks (e.g., regulatory, social, economic, political). The exercise involved undertaking trend analysis for all risk categories and developing scenarios by providing different contexts for each region of expansion so strategic investment decisions can be made with these issues in mind at global level. The process helped to identify "red" and "green" flags in their expansion strategy, ideas, and management options for dealing with risks in existing operations and priority areas that might need additional investment in response to issues as influence by climate change among other interconnected risk sources.

Most corporate risk departments already run scenario planning exercises. There is a need for this process to take into account climate change, climate risk, and broader sustainability aspects as they become material issues for doing businesses. The risk management process can be enhanced by integrating climate change and sustainability issues into company's risk management and strategy and by deepening skills in systemic thinking. Scenario planning, used in this way, can then be seen as a key activity for developing the future leaders, giving them the understanding and skills to help shape the future direction and philosophy of the business.

Step 3: Develop the Business Case for Adaptation

Managing climate risk involves intervening in the system and implementing adaptation measures which alter the flow and feedbacks within the system. A comprehensive understanding of how the system functions is essential to ensure holistic solutions are identified which minimize unintended negative consequences. The value generation and climate risk mapping undertaken in Step 2 will provide valuable input to this process.

Intervening in a system means understanding the critical relationships and focusing interactions with these. It means taking account of the intended and unintended consequences – positive and negative – that result from these interactions and consequences in different interconnected parts of the system; the "problem" may well be a symptom of a problem elsewhere. It means being alert to and able to see and detect patterns that emerge and are unintentional as well as those that are designed and intentional.

The individual risks identified in Step 2 should be considered in relation to the web of impacts, with the aim of increasing the coping threshold increased through identification of adaptation measures to prevent, minimize, and/or mitigate the risk. Key is identifying a small number of measures which address a large number of risks.

The type of intervention selected depends on the site-specific nature of the problem and the extent to which it is connected with other impacts. Figure 9 outlines various types of adaptation approaches, and examples of how these can be used to manage water scarcity.

The potential avoided loss and the capital cost of implementing each option should be quantified and analyzed against the cost of the risk determined in Step 2 in order to create the business case for adaptation.

Once the adaptation options to mitigate climate risks have been identified, realistic costs should be estimated, input to a cost-benefit analysis (CBA), and contrasted against the potential averted losses from impacts analysis in Step 2. The CBA aids the decision-making process by giving monetary values to the risks and opportunities and enables a comparison of like quantities. A CBA can help companies in making decisions on whether previously identified adaptation options are reasonably practicable.

Adaptation options aimed at reducing risk linked to extreme weather events can also be evaluated on the basis of their internal rate of return and make the business case for themselves as with any other type of investment.

An example of a water scarcity adaptation investment curve for a mining complex is provided in Fig. 10. It presents a list of adaptation options by positive or negative return of investment (y-axis) and the cumulative expected averted losses in $million (x-axis).

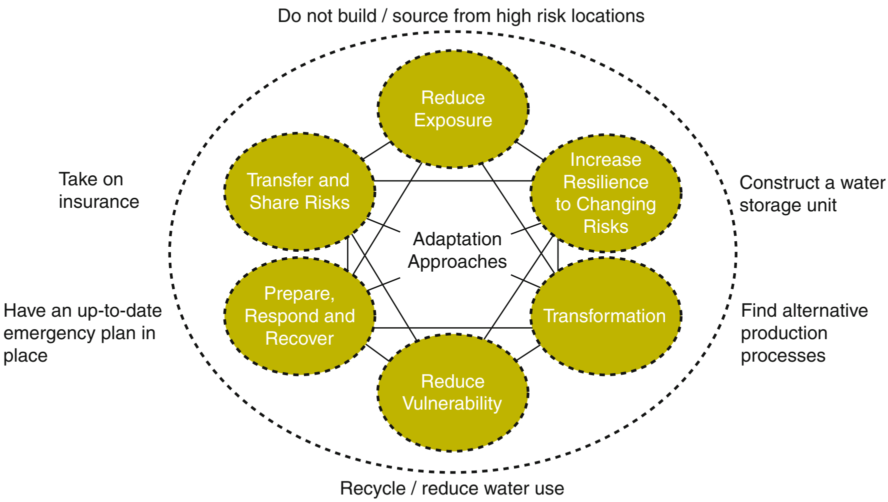

Fig. 9 Types of adaptation approaches with examples relating to drought (ERM 2012; IPCC 2012)

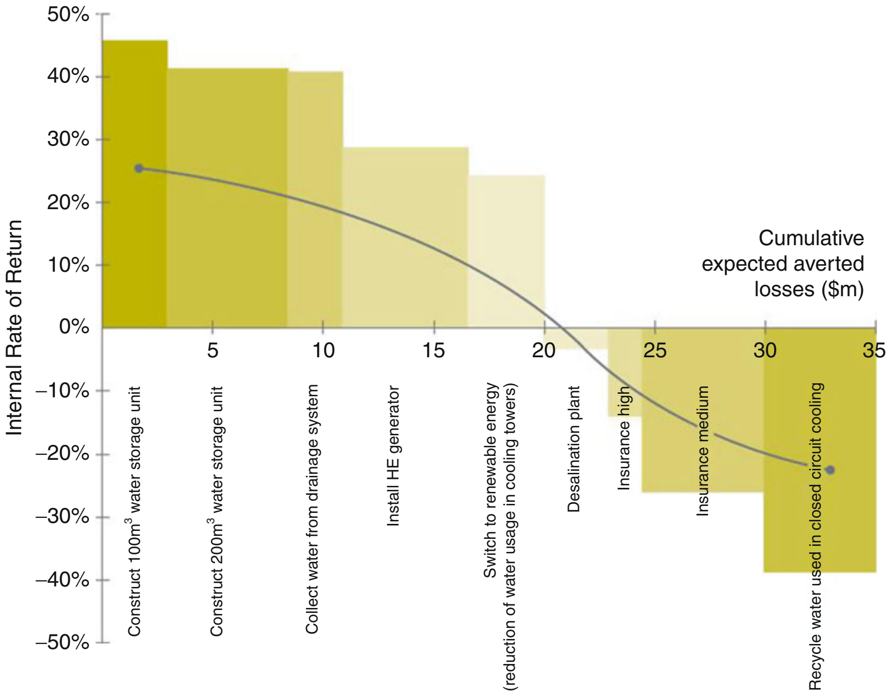

Fig. 10 An example of an adaptation investment curve in relation to water scarcity

Although there is uncertainty associated with the timing of impacts that could represent challenges when calculating the return on investment of adaptation options, companies still find this a useful tool to prioritize and present results to senior management in a clear and concise manner.

Furthermore, sensitivity analysis with regard to the timing of impacts can be undertaken to better describe the uncertainty associated with the investment profile of adaptation options.

It is important to note that financial analysis should not be the only decision-making tool for evaluating adaptation options. In some cases, there will be unquantifiable risks and benefits which need to be considered such as those linked to social and environmental outcomes. It may be that a higher cost option has more unquantifiable benefits than a lower cost option which makes it the preferred course of action as described in the case study below. All the above should be taken into consideration in order to formulate an effective intervention strategy for climate change adaptation.

Case Study Flooding regularly occurs in and around a mining complex in South Africa. The mine is surrounded by local communities housing mine workers and their families and other mining companies. Focusing on managing flooding and storm water discharge within the boundaries of the mine complex misses an opportunity to work with other companies in the area to develop an integrated water management plan and to help reduce the vulnerability of local communities – particularly the informal settlements in the floodplain which are destroyed on an almost annual basis. Collaborative working and a low additional cost could potentially enhance the quality of life for the mine's workforce significantly, in addition to providing a more sustainable solution to water management in a water-stressed area.

Step 4: Create an Adaptation Strategy

The Strategy Development Process

The management of climate risk and adaptation within organizations currently sits somewhere on the continuum illustrated in Fig. 11. The aim of an adaptation strategy is to move toward embedding a systematic approach to climate risk and adaptation into business practices. How an organization chooses to do this depends on the nature of the risks identified, the business case for adaptation, and the company values/ambitions. An adaptation strategy will provide clarity and direction for the steps to address climate risks and opportunities.

Traditional strategy development involves the exploration of the answers to the following questions:

- Where are we as a business today?
- Where are we do we want to be in X years?
- What are the key climate change issues that our business (or project) strategy needs to address now and in the future?
- How can we best position ourselves to take effective action?

The outcomes of steps 1–3 above should provide a wealth of inputs to feed into the standard strategy development process outlined above. Optimization of the outcomes, however, comes with the adoption of a systems approach to strategy creation and organizational leadership.

Fig. 11 Stages of integrating management of adaptation in organizations

In developing a strategy, it is critical to "get the whole system in the room" in order to understand it, engage with it, and see how and where it is relevant for the organization. Rather than seeing strategic planning as the preserve of the "numbers people," collaborative tools for strategy making become essential here in order to bring together all those affected within the system and on the systems boundaries and to engage them in understanding the nature of the situation and its implications. Data and analysis come to the process as inputs, but the key is bringing together different functional disciplines, stakeholders, and generations to interpret the data through multiple lenses and to obtain the deepest insights and uncover solutions to which all players can commit.

The value generation process illustrated in Fig. 5 provides an example of the various connections and interconnections between different elements of the business system. These elements are affected by impacts and adaptation measures and should be considered when developing an adaptation strategy in order to ensure that management of climate risk and the leveraging of opportunities occurs in the most appropriate fora. The strategy that is developed is not only a strategy for the company adapting to climate change but impacts the broader business environment in which the company exists. It recognizes interdependencies between players, climate, and time and puts a value to these.

Finally, the strategy should look to ensure that the organization maximizes opportunities and enhances resilience in the short, medium, and long term depending on the nature of the impacts it is dealing with. This will help ensure that future expenditure and planning take place with an "adaptation lens" and that consideration of climate risk and adaptation is fully integrated within business processes.

The Process and Skills Required

Developing an adaptation strategy this way requires leaders and managers to have a level of fluency in systems thinking or the willingness to acquire this mindset and associated skills. The mindset and skills can be seen as a distinct portfolio of:

- Recognizing systems boundaries
- Perceiving interdependencies in and between systems
- Appreciating the dynamics that underpin complex systems
- Seeking out the points of greatest influence within a system and designing and implementing interventions at these points
- Staying alert to the unintended as well as the intended consequences and responding to these in a way that optimizes outcomes

This portfolio can enlarge the traditional expectations of business leaders around vision and strategy, planning, and execution. It can enable leaders to navigate more effectively through increasingly volatile, uncertain, complex, and ambiguous times and find the right path to address the significant problems that face not only their business but also their broader communities and the Earth.

Using the systems approach as a leadership practice as well as a tool to understand how climate change might influence the relationships within the business system is the key element of the strategy making process and will be what ensure its implementation and sustainability. So a company should ensure that its future managers and leaders participate in the strategy development process, because it is these individuals who need to:

- Own it, be committed to it, and take it forward.
- Understand the climate-related risks and opportunities from a systems perspective, such that this becomes integrated into their way of understanding the business context in which they are operating and that they act from this standpoint.
- Develop and deepen relationships with other stakeholders and build the reservoirs of trust that ensure effectiveness. Trust is the glue that ensures that when unforeseen things happen, stakeholders draw together, rather than pull apart, and find the right path forward together.

Framework for an Adaptation Strategy

The form of a climate change adaptation strategy depends very much on the nature of the business and the values of the company. Ultimately it should become an integral component of corporate strategy development rather than a stand-alone document as this will ensure proper integration with day-to-day activities. To this end, the strategy should build on the company's existing values and policies and focus on priority areas for action. An example of how a strategic implementation framework for adaptation is outlined in Fig. 12.

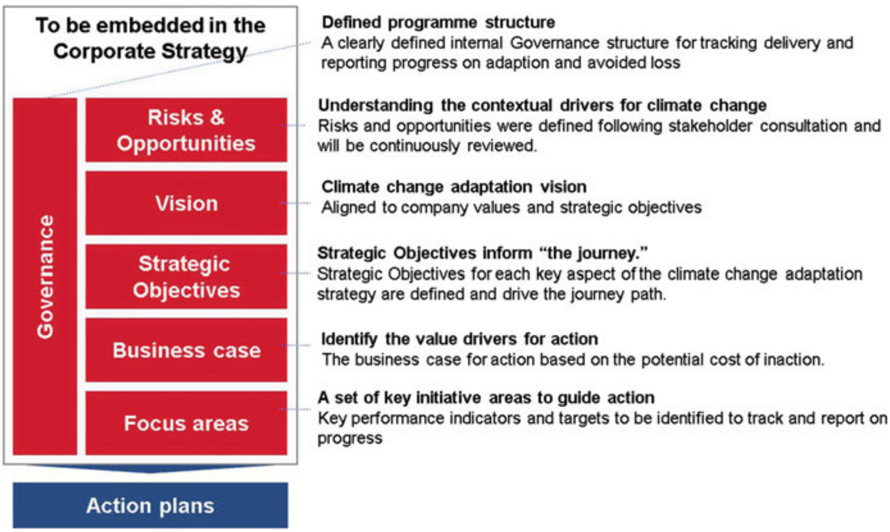

Fig. 12 Example of a strategic implementation framework for adaptation

Conclusion

Climate change poses complex challenges for business not only because of uncertainty associated with the timing and the magnitude of projected changes but also because of the interconnectedness between risks and impacts in the modern globalized economy.

There are traditional approaches for assessing and managing risks and these can be supplemented and further analyzed with *systems thinking*. Traditional risk management techniques can help manage and adapt to the operational risks amplified by the changes in the frequency and severity of extreme weather events. However, understanding of risks and their boundaries within a system and how they influence one another and manifest in impacts within a value-generating system is of paramount importance.

Understanding the impact of climate change on an organization or site might seem like a daunting task, but focusing the activity in a few simple steps will allow for comprehensive analysis of the business case for undertaking adaptation and the development of a strategy for managing climate risk in the future. The four-step approach outlined below aims to provide guidance on where to find information and how to interpret it within existing business processes. It draws on the systems approach to ensure that the full range of risks and opportunities are considered and that holistic approaches to managing and leveraging these are identified:

- Step 1 – Understand the climate change context within which the company is and will be operating through analysis of historic and projected climate data.
- Step 2 – Assess the risks and opportunities that are linked to future scenarios.
- Step 3 – Develop a business case for adaptation through simple economic analysis.
- Step 4 – Create a strategy to ensure consideration of climate risk and adaptation is fully integrated within business activities.

Long-term climate changes tend to be systemic with a wide web of impact connections and can bring risks and opportunities of a different scale. Resilience to risks or positioning to enhance opportunities can be built by taking a more holistic *systemic* and *scenario planning* approach to managing climate change and enhancing traditional risk management approaches. By “seeing the wood for the trees,” managers can identify the practical actions required to manage climate risk, and business leaders are provided with tools to help ensure that their companies are proactive in understanding and managing climate risk and adaptation and leading the companies in the “path of least resistance.” And last but not least, this process is not only about identifying immediate issues and finding solutions but also going through the process itself, building leadership skills, and transforming for organizations and individuals engaged in this process and acquiring a new “systems thinking lens” of the world.

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Understanding Impacts of Climate Variation in Varied Socio-ecological Domains: A Prerequisite for Climate Change Adaptation and Management

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Contents

Abstract

This chapter examines the impacts of climate variability on selected socio-ecological settings in South Asia. A transdisciplinary conceptual framework is presented that blends multilevel interactions in a social-ecological-climate nexus.

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The overarching objective is to draw on empirical experience to build capacity to make use of climate data for societal needs, i.e., to facilitate climate change adaptation planning. The chapter has two modules. The first module, Climate Change Monitoring (CCM), details the operating structure of real-time climate data and its practical use. The second module, Climate Change Assessment (CCA), examines impacts and adaptation options using a case study approach. Focusing on the analytical process, the authors examine three socio-ecological subsystems, i.e., marine fisheries, a rice agroecosystem, and human migration, using a mixed "tool box" of meteorological data, remote sensing images, primary and secondary socioeconomic information, and a variety of software programs. The results indicate that (1) spatial indicators are useful in explaining a decline in marine ecosystem productivity; (2) local-level temperature variability is closely related to agroecosystem transitions; and (3) climatic variability, especially increased frequency of extreme events, triggers human migration. The case studies highlight the need to employ real-time climate data in the design of adaptation strategies and the requirement for a transdisciplinary approach.

Keywords
Climate variability and change • Adaptation • Socio-ecological systems • Transdisciplinary

Introduction

Climate change is acknowledged as a key environmental problem worldwide. Global assessments have classified South Asia as the region that is most vulnerable to the impacts of climate variability and change. To this end, science-based evidence, integrated approaches, and a transdisciplinary mind-set are crucial to ensure that adaptation measures taken are appropriate and effective. The rate of change of climatic processes is such that ecological and socioeconomic systems are shifting toward critical thresholds, a process that in due course will modify the global environmental balance at multiple scales (UNEP 2009). At the same time, the increased frequency of unusual climate events in the recent past has stimulated the scientific community to explore their impact on the stability of earth systems (FAO 2008). Many researchers agree that some climate parameters may well have already crossed critical tipping points, in a process that is irreversible and raises serious concerns for the future of human civilization (Kriegler et al. 2009; Lemoine and Traeger 2011). Climate change is a major overriding environmental issue of our time and particularly a great challenge facing conservation and development managers. It is a mounting crisis in multiple dimensions such as health, economics, and food production/security (quoted, Ban Ki Moon, United Nations Secretary General in his address in 2008).

There is increasing empirical evidence of the impacts of climate change, including abnormal rainfall patterns, increasing surface air temperatures, cyclones, tidal surges, floods, sea level rise, and saline intrusions in coastal areas. These lead to the disruption of environmental and ecological services and loss of livelihoods and thus provoke human mobility. Climate change adaptation measures, including technological aid, financial instruments, and policy, need to factor in the diversity of climate-driven impacts. The gravity of the current situation, the associated uncertainty, the inadequate knowledge, and the manifold impacts of climate change, both anticipated and unanticipated, all point toward the critical need for climate management and adaptation strategies to align with social and economic development agendas (World Bank 2010). To this end, it is important that the socioeconomic consequences of climate change are examined together with other impacts. Integrated transdisciplinary approaches can help deal with the uncertainties associated with climate change assessment and prediction (Nagabhatla et al. 2012).

Global efforts to plan and execute effective climate adaptation measures in accordance with relevant mandates require collaboration between the scientific community, government agencies, and development practitioners, in order to identify and address the principal challenges involved (UNFCCC 2009). A first challenge is to ensure the availability, accessibility, coherence, and accuracy of the relevant data. A second is to foster the necessary expertise and build capacity to analyze data as required for the fulfillment of the defined objectives. A third is to develop the ability to assimilate multiple levels of information, in order to assess the impact of climate change and diagnose the inherent adaptive capacity of the system that is affected (a socio-ecological system in this article). The extent to which one succeeds in addressing these and other challenges will determine the relevance of research and practical initiatives promoting adaptation to climate change (World Bank 2010). Furthermore, downscaling climate information to align with grassroots level research is required to elucidate local-level interactions. This is vital for vulnerability assessment in the framework of climate change adaptation initiatives (Johnston and Williamson 2007). For instance, in order to assess the vulnerability and resilience of a socio-ecological system, information is required on the impact of climate variability on livelihoods (sensitivity), potential risk scenarios at seasonal temporal scales (exposure), and inbuilt coping strategies (adaptive capacity) (Miller et al. 1999). It is essential to take account of climate-related uncertainties in natural resource decision-making and management policies (Banuri et al. 2001). This is a challenging undertaking, since climate dynamics vary at different scales (global, regional, and local) and in different geographical settings; tropical systems in particular are very complex in these respects (Nagabhatla 2012).

Efforts are required to compile and analyze the experiences of initiatives that aim to link modeled and observed information at different spatial scales (Nagabhatla et al. 2012). Scientific research projects and programs involved in testing the competency and compatibility of data models, predictions, and forecasts should widen their objectives to consider not only trends but also patterns of climate irregularities and their potential impacts on natural, social, and economic systems (Hasselmann 1993). To this end, institutions and organizations that produce climate data and develop climate models, such as the Asia Pacific Climate Center (APCC), could act as hubs, fostering partnerships and collaborative initiatives. The APCC aims, through its various new programs, to transfer climate knowledge to a vast set of users. However, experts from the institution point out that packaging climate data in a format that can be applied by experts from different sectors and disciplines is a very challenging task; indeed, it may involve a total recalibration of data and models. The APCC data service system (ADSS) offers a comprehensive set of models and observational climate data for a variety of applications that include monitoring evolving climate events and issuing sub-seasonal to seasonal long-lead forecasts. It also provides a platform for the creation of customized forecasts and analyses of sub-seasonal/seasonal climate variability and predictability (Wang et al. 2009).

The descriptions of case studies in this chapter were produced either in direct collaboration with APCC or by employing their range of real-time climate products. The main datasets employed included satellite-derived earth observation images, climate data, outputs of hindcast and forecast models, and secondary socioeconomic information. It is commonly stated that complex challenges require complex solutions (Ward et al. 2011). With this understanding, the authors employed socio-ecological system as a unit for analysis. The term socio-ecological domain or system is used to refer to a space where natural and social capital interact (Nagabhatla and Kumar 2013). Socio-ecological systems are highly diverse and differ in how they impact or are impacted by climate variability and change (Daw et al. 2009). They are thus appropriate units of analysis for the study and assessment of impacts of climate variability, enabling a contextual understanding of climate-related risk and patterns of extreme climate events. This is a prerequisite for effective climate management, since climate change adaptation measures (interventions, decisions, policy, and governance) must be based on a clear understanding of how natural resource and socioeconomic dynamics interact in their area of application. Analysis of the functional association between climate and the social and economic spheres is as essential as biophysical assessment for effective adaptation to climate change; this applies to local-level initiatives as well as larger-scale programs. The methods discussed here sometimes involve simplifying or deconstructing climate knowledge, as the aim of authors is to highlight how an inter-/transdisciplinary mind-set can prove particularly helpful for their application.

The (Right) Questions

In order to understand the impacts of climate variability in varied socio-ecological domains, it was crucial to ask the relevant questions. A transdisciplinary approach is a prerequisite for planning effective climate change adaptation and management programs. Impressions and perceptions from different stakeholders, both from scientific and nonacademic sectors, are required inputs for the design of a transdisciplinary framework. Based on the above understanding, the following questions were formulated and constitute the overarching focus of this chapter.

1. What kind and type of climate information is important for climate change assessment and monitoring climatic processes?
2. What kinds of approaches and methods show potential to integrate climate-related issues in projects and programs?
3. What kinds of climate processes (abnormal or extreme events) define critical situations, and which climatic parameters are of significance for study of such situations?
4. How can climate data (past trends, current climate dynamics, and future predictions) be used to overcome barriers to adaptation and facilitate effective interventions?

Holistic approaches, as showcased in this chapter, can contribute to improved understanding of multiple layers of knowledge derived from meteorology, satellite data, statistical analysis, and socioeconomic information and, above all, from the interaction of experts from these disciplines working together.

Structural Arrangement of the Study and the Study Area

The first module *Climate Change Monitoring (CCM)* provides a general overview of annual, seasonal, and interannual climate trends at regional and local levels. Hindcast analysis is employed to highlight the variability of two key attributes: rainfall and surface temperature. This module also discusses the potential of forecast information. The APCC's climate information product Multi-Model Ensemble was compared with observation data to assess its usefulness. The second module *Climate Change Assessment (CCA)* adopts a case study approach to explore the impact of climate variability in diverse socio-ecological settings. The selected socio-ecological subsystems are the marine fisheries sector in Bangladesh, a rice agroecosystem in Southern India, and human migration induced by climatic and environmental changes in Bangladesh. The selected systems are very different from each other in many respects; however, food production, livelihoods, and adaptation to climate change are key issues in all three cases. Focusing on these issues, the chapter outlines a conceptual framework for analysis and assessment of climate-led impacts and discusses how up-to-date assessment can facilitate adaptation measures.

Area of Interest: Bangladesh and India

The focal area is South Asia, specifically Bangladesh and India. Consideration of the different socio-ecological circumstances in these two countries highlights the significance of regional and local analysis for climate change monitoring and assessment. Bangladesh is one of the most climatically vulnerable regions of South Asia (Rahman et al. 2007). Agriculture and fisheries are the main sources of natural resource-based livelihoods. About a decade ago (2000–01), marine capture fisheries in Bangladesh, whose territorial waters cover an area of 166,000 km^2, amounted to nearly 22 % of total fish landings in Bangladesh, a proportion that has, however, declined in recent years (Flewwelling 2000). Climate-induced changes, particularly sea level rise, put 12 of 19 districts in the country (>60 % of total land area) at risk, while seasonal flooding represents another big threat to the country's social and economic well-being (Litchfield 2010).

Bangladesh, with its multifaceted challenges, is a prime case of climate-induced threats to human livelihoods. A related concern is the risk of increased climate-induced human migration, both internal (within national borders; those affected are referred to as Internally Displaced People) and external (outside the national borders, generally regarded as refugees). The IPCC's Fourth Assessment Report (2007) reflects on the intensity of human migration that may possibly be triggered as the result of climate-induced changes. For instance, a 1m sea level rise could displace 14.8 million Bangladeshi people, while inundating an area of 29,846 km^2. Recent years have also witnessed an increase in the frequency and intensity of extreme climate events. Many of these exposed a high proportion of the population to coastal and inland floods caused by cyclonic and tidal surges. Growing apprehension for the future of natural resource-dependent livelihoods such as agriculture and fisheries is shared by the development community, resource managers, decision makers, and scientific experts worldwide. However, no clear strategy to address these concerns is yet in place. The country is the focus of attention of global climate experts, both for assessment of the impacts of climate change and to provide guidance on adaptation.

India, with its complex diversity of ecological, social, and economic systems, is also classified as vulnerable to climate-induced changes (Sivakumar and Stefanski 2011). The levels of exposure, impacts, and adaption measures vary among different biophysical and geographical regions. This makes it difficult for experts to arrive at a comprehensive assessment of the impacts of climate change and increase challenge to manage them effectively. As an example of this complexity at local level, described is the rice crop-dominated agroecosystem of Wayanad district in Kerala, South India, an area covering nearly 2,000 km^2. The sociocultural diversity, particularly among the tribal population, is a point of special interest for this region. In recent years, agrarian land use patterns have undergone a notable transformation; with local farmers increasingly opting for cash crop production in preference to the traditional small scale and subsistence rainfed rice cultivation.

Agriculture statistics provide evidence of a steady decline in the area under rice cultivation in Kerala, including Wayanad, since the 1970s. In some areas, this decline is more than 50 % (Nagabhatla and Kumar 2013). Many explanations for such dramatic changes have been put forward by researchers, as well as by local authorities and farmers. In summary, the principal drivers of change may include the development plans that lack holistic insight to balance ecological sustenance and economic stability; the disturbance caused by natural and anthropogenic changes to the environment, climate variability, and change (i.e., fluctuations in onset and amount of rainfall); the relative economic costs of crop production; and the lack of irrigation facilities to meet the growing demand for water. The description in this chapter will focus on climatic variability as the driver of change in agrarian land use.

Module 1: Climate Change Monitoring-CCM

While numerous atmospheric elements influence the environment-human-climate interface, precipitation (rainfall) and atmospheric temperature are considered among the most important dimensions of local-level weather and climate patterns. Real-time climate data is a key resource for the analysis of climate variability. Simulations, predictions, and forecasts provide additional inputs for the interpretation of climate history, typology, and trends, while decision support systems (Crossland et al. 1995) can help translate this scientific knowledge for use in planning practical adaptation interventions (Rizzi et al. 2012). The authors explore this potential with reference to the Indian subcontinent, comparing observed and modeled climate information. The discussion highlights the significance of format, periodicity, spatial, and temporal scale when using real-time data and considers the relevance of predictions and forecasts for adaptation planning.

With regard to forecasting, dynamic seasonal forecasts have potential for use in prediction and monitoring of extreme climate events, including droughts and floods (Luo et al. 2007; Nagabhatla 2012). While prediction and monitoring of climatic trends are demanding processes and the results are subject to a good deal of uncertainty (Hannart et al. 2009), global efforts to understand climate dynamics have benefitted significantly from advances in computerized data analysis, monitoring, and modeling. Wang et al. (2009) describe the initiative by APCC to create a Multi-Model Ensemble (MME), a model-based "output" employed in weather and climate forecasting.

The derivation of MME requires a theoretical analysis of an assembly of deterministic forecasts and typically employs spatial filtering for each variable at each grid point (Wang et al. 2009). In short, appropriate characteristics of several independent models are combined to derive an MME. Tested is hindcast simulation of MME (6 M-1-tier) experimental (downscaled) forecast data based on six coupled models with an annual frequency of 4, i.e., February (MAMJJA, from March to August), May (JJASON, from June to November), August (SONDJF, from September to February), and November (DJFMAM, from December to May), with a resolution of $2.5 \times 2.5°$ at the global domain (144×73 grid) scale, against observation data for Indian region. The hindcast of monthly means for 27 years (1982–2008) was compared with observation values and demonstrated good ability to capture a reasonable portion of rainfall variability on the Indian subcontinent. However, key climate events such as floods were not always captured with high accuracy (Fig. 1a). The level of agreement between the observation data and MME-derived values provides a measure of the capacity of the model ensemble to capture climate phenomenon. Further, the same MME provides inputs for prediction experiments, and the forecast data is available from 2008 onwards (Fig. 1b). Forecast information is a vital component for adaptation planning.

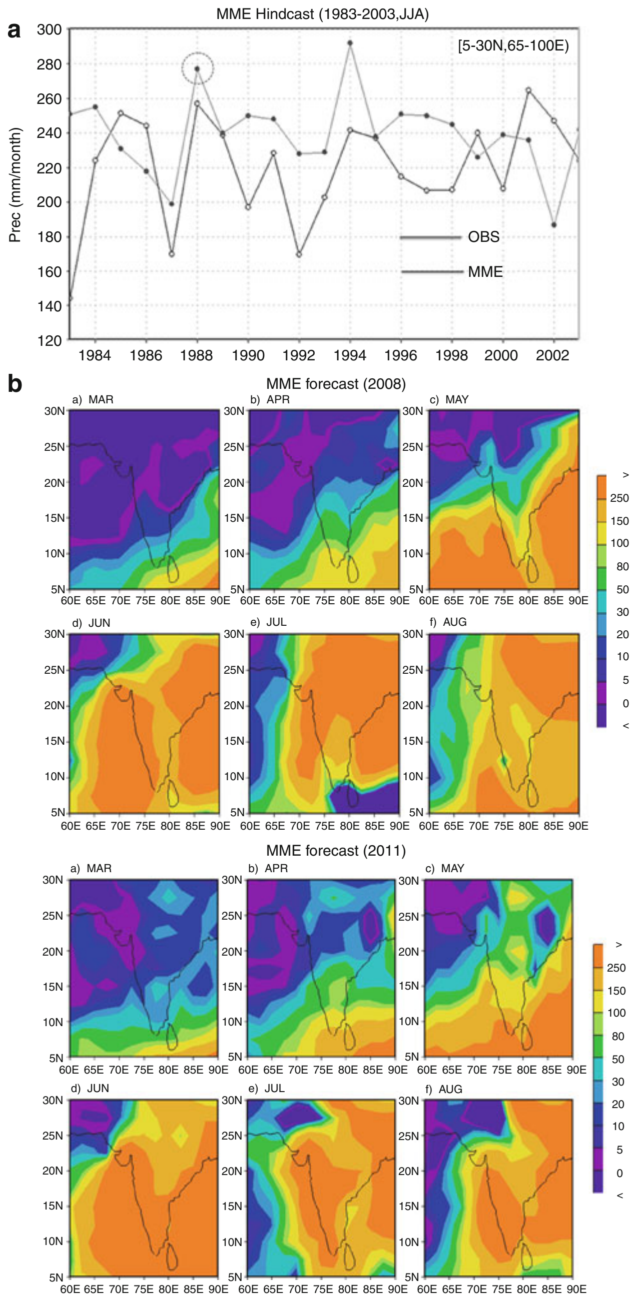

Fig. 1 Multiple dimensions in CCM – part1. (**a**) Modeled data versus observation: MME hindcast tested with rainfall data for India; (**b**) MME forecast for 2008 and 2011 for the Indian region

Currently, only a limited number of the coupled forecasts and ensembles are available for application across different sectors. Improved methods for configuring ensembles are a vital need and remain a long-term goal to enable wider application of climate information across multiple sectors such as agriculture, water management, conservation, and so on (Nagabhatla 2012). The quality of MME depends on the climate models selected to create the ensemble and on whether the selected climate models assimilate the parameters required to capture climate phenomena that are relevant for a particular sector or application. Coupling climate prediction data with resource-specific attributes (ecosystem, socioeconomic, hydrological, etc.) represents a promising way forward to create realistic and practically useful prediction and forecast scenarios. This in turn will help build capacity to cope and respond to change, i.e., contribute to adaptation.

Turning now to the significance of observation data, one may note that climate variability is often expressed as temperature or precipitation fluctuations in a space-time continuum. For up-to-date monitoring of precipitation trends, access to observation rainfall data is necessary. The data is accessed from the web interface of Indian Institute of Tropical Meteorology (http://www.tropmet.res.in). The national-level (for India) data included annual anomaly values for the years 1870–2005 from 316 rain gauges stations and could be conveniently arranged into four seasonal slices (Sontakke et al. 2008): summer (MAM-March, April, and May), monsoon (JJA-June, July, and August), post-monsoon (SON-September, October, and November), and winter (DJF-December, January, and February). Trend analysis is a convenient way to get an impression of shifting or changing climate regimes. The seasonal rainfall trends showed a declining trend in rainfall during the summer monsoon – an observation broadly in agreement with South Asia scenario of Cruz et al. (2007), whereas pre-monsoonal rainfall showed an increasing trend. Correlation analysis of rainfall variation for JJA with frequency of flood and drought events (source: NRAA-2013) provides evidence of increased frequency of droughts and negative rainfall anomalies, especially after the 1960s (Fig. 2a). A research compilation by Mirza (2003) supports the above observation, showing that while many parts of Asia have witnessed both floods and droughts in recent years, the overall trend shows a decline in the number of rainy days and the annual total precipitation.

Similarly, centennial (1901–2001) trends in temperature ($T_{(max)}$ for summer and $T_{(min)}$ for winter) for the east coast of India show increases for all seasons (Fig. 2b shown only for MAM). In the same context, Lal (2003) notes the increasing frequency and intensity of droughts in the region and attributes this trend to the overall temperature increase (especially during summer), as well as to the influence of large-scale climate processes such as ENSO (El Niño-Southern Oscillation). Seasonal prediction of the monsoon phase is crucial for effective application of climate information for adaptation planning and other purposes. Nevertheless, the impacts of climate dynamics vary with sector, scale, and geography and inter-/transdisciplinary collaboration is essential for the adaptation process to be operational and effective. If society is to make use of prediction and forecasting information to design practical adaptation strategies, it is important to understand the multifaceted nature of climate processes (Fraisse et al. 2006).

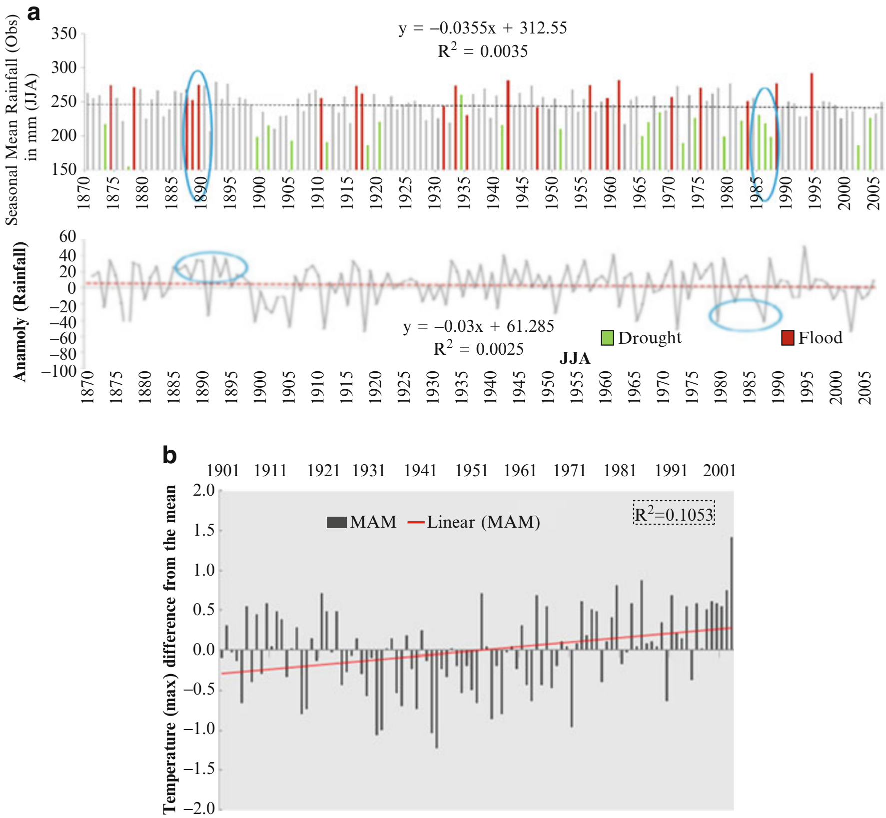

Fig. 2 Multiple dimensions in CCM – part 2. (**a**) Monsoonal rain (JJA) distribution pattern and anomalies from 1870 to 2005; drought and flood events are highlighted as green and red bars, respectively. (**b**) Centennial trend in summer temperature (anomaly) in east coast India showing a clear increase

Module 2: Climate Change Assessment-CCA

This module explores the impact of climate variability and change on three socio-ecological systems.

Case Study 1: Fisheries, a Sector of Social and Economic Significance

A recent report of the Environmental Justice Foundation (EJF 2012) confirms that Bangladesh is under stress from multiple factors including escalating population, unregulated economic development, transboundary conflicts and, of late, the mounting threat posed by changing climate dynamics. Nagabhatla et al. (2012) describe how annual flooding during the monsoon is becoming more widespread and severe, sometimes submerging nearly one fifth of the country. The impact on communities dependent on natural resources for livelihoods is evident; the direct and indirect impacts of floods on the productivity of marine and freshwater fisheries and the livelihoods of fisher folk are particularly severe (Daw et al. 2009; Nagabhatla et al. 2012). Inland and marine fisheries are a vital sector for the nation's food, livelihood, and economy, making it vital to take steps to mitigate the impact of climate variability on fisheries. To this end, improved knowledge is required on how changing seasonal climate patterns and climate variability affect marine fisheries and specifically their resource-climate-social nexus. This case study explores the potential of real-time climate data to contribute to this understanding.

Technological advancements combined with political and institutional support have helped increase the contribution of the fisheries sector to the gross domestic product of Bangladesh (Deb et al. 2008). However, fisheries resources management has not been able to keep pace with the changing situation brought about by the increased frequency of atypical climate events in Bay of Bengal (BoB) region. Marine fisheries in particular (and the overall functioning of marine ecosystems) have suffered from the atypical behavior of large-scale climate phenomena such as Indian Ocean Dipole and El Niño and their effects on coastal and atmospheric circulations (Ashok et al. 2001). Concern for the future of fish-based livelihoods in Bangladesh is increasingly voiced by the media, development agencies, and national-level authorities (Goswami 2013).

Annual fish production in Bangladesh rose from one to nearly eight million tons in the 50 years to 2010, with sizeable contributions from all sectors: inland, marine, and coastal (Fig. 3a). However, in recent times, the contribution from marine sector has remained static or shrunk. Using secondary data, i.e., records of the Department of Fisheries, Bangladesh, the authors charted the evolution of fisheries landings from 1979 to 2010 in Bangladeshi waters in the BoB region between 5–30°N and 65–100°E. This is the key zone sustaining the majority of the country's marine fisheries (Fig. 3a). The available data covers two historical periods: pre-mechanized (1979–1997) and post-mechanized (1998–2009), i.e., after the introduction of trawlers. The analysis focused on the post-mechanized period. Marine fish productivity was calculated as fish catch per fishing trawl (Fig. 3b).

The remote sensing project SeaWiFS (Sea-Viewing Wide Field-of-View Sensor) is an earth observation mission of NASA (http://www.nasa.gov/) that stores and processes data on global ocean bio-optical properties. Of particular interest for the present study were the data on Chlorophyll (*Chll*-a) concentration, which can be taken as a surrogate of marine biomass. Two other significant attributes that affect the atmospheric and hydrodynamic balance of marine ecosystems areas are sea surface temperature (SST) and sea surface height (SSH). The *Chll*-a data was obtained from SeaWiFS monthly records accessible at the web interface (http://oceanwatch.pifsc.noaa.gov), SST data from NOAA-OISST (National Oceanic and Atmospheric Administration, Optimum Interpolation Sea Surface Temperature), and SSH records from the Archiving, Validation, and Interpretation of Satellite Oceanography (AVISO) data service of the Asia Pacific Data Research Center (APDRC). To evaluate Chll-a, SST and SSH variations over the 12-year period (1998 – 2009) during three 307 seasonal slice, September – November (SON), December – February (DJF), and March – May (MAM), a linear regression-based trend analysis was employed (Fig. 3c).

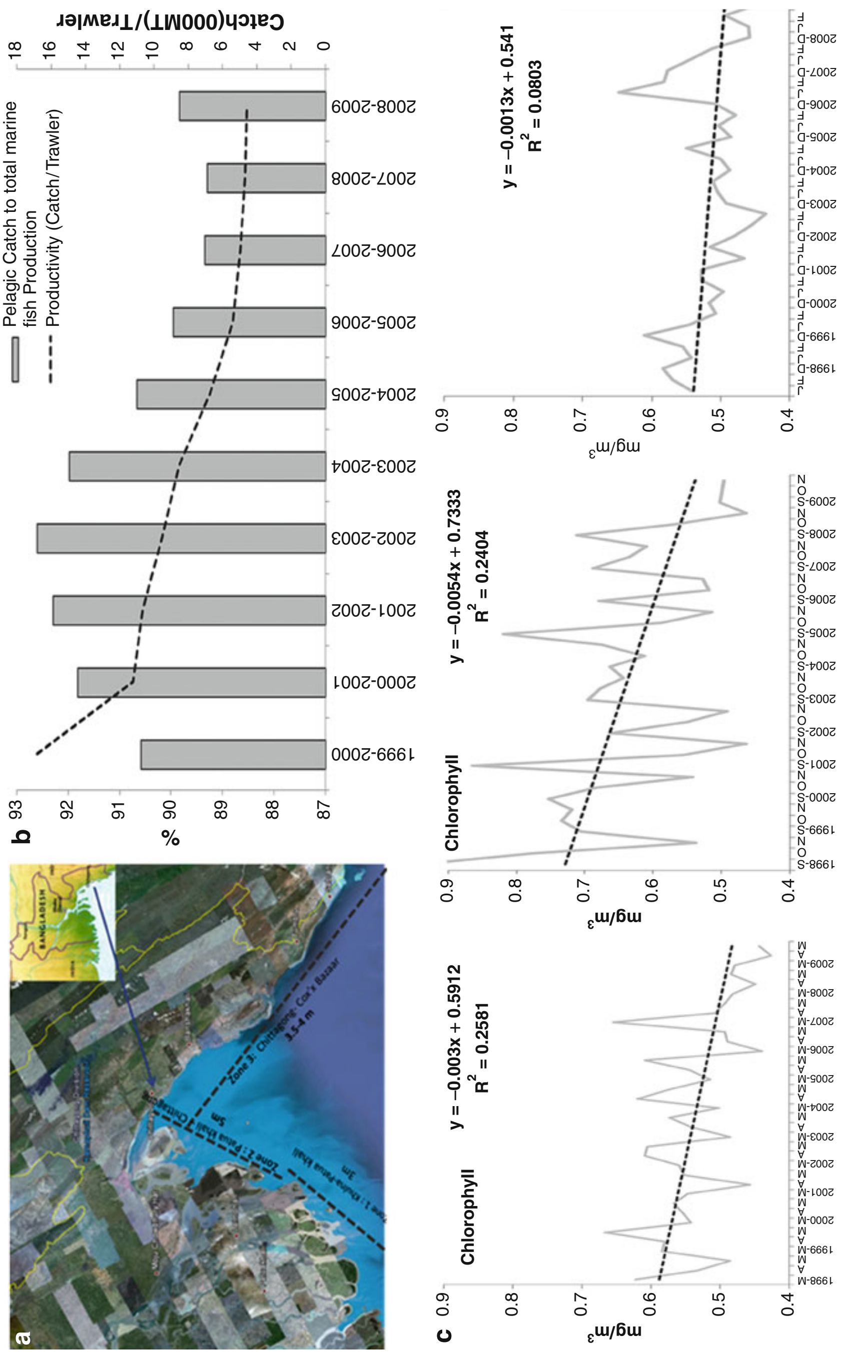

Fig. 3 (continued)

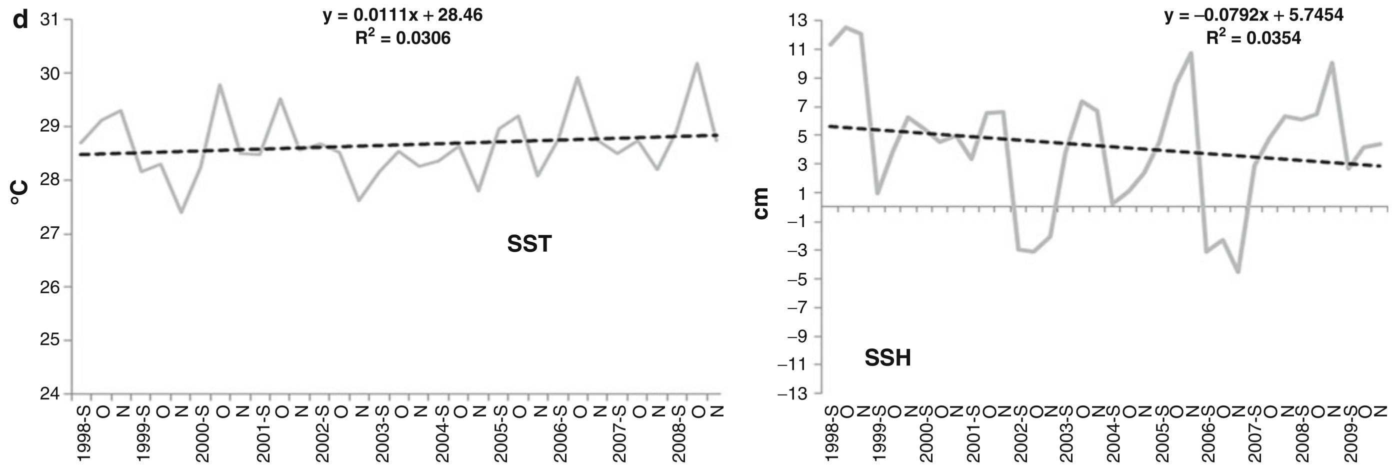

Fig. 3 (**a**) Area of interest – Marine territorial zone of Bangladesh; (**b**) temporal trends in marine fish productivity (1999–2009), measured as catch per trawler; (**c**) distribution of chlorophyll concentration in the BOB region of Bangladesh. Marine fish productivity and chlorophyll concentration both show a declining trend in the temporal slice (1998–2009) under consideration: (**d**) SST and SSH variance in the Bay of Bengal region during SON (inversely related)

The analysis revealed an overall declining trend in marine productivity, shown by a fall in C*hll*-a concentration by almost half, from 0.95 to 0.50 mg/m^3 during SON. However, there was marked variation among seasons, and the decline in *Chll*-a concentration during SON was much greater than in DJF or MAM. In line with the decline in marine productivity, the contribution of marine fish production to total fish production in Bangladesh over the last decade has declined from 20 % to 17.5 %. The decrease in chlorophyll concentration can be explained by the increasing trend of SST, which was of the order of 0.1–0.25 °C during DJF and SON (Fig. 3d, shown only for SON).

These results suggest that the warming climate is disrupting oceanic hydrodynamics and the related marine ecology. The increase in SST can in turn be partially explained by the corresponding trends in SSH, both annual and seasonal (Fig. 3d, shown only for SON). Typically, SST and SSH are inversely related; however, during MAM, there is a direct relationship that could reflect the influence of pre-monsoonal local oceanic circulatory processes and currents, together with the effects of land-sea-atmospheric interactions. These seasonal variations likely affect the marine ecosystem and more specifically fish productivity in the BoB region.

The analysis shows how climate observation time series data derived from satellite remote sensing technology can shed light on the complexity of marine ecosystems. In this case, secondary data on fisheries production complimented the satellite-derived spatial oceanographic information. A large proportion of people in Bangladesh depend on marine fisheries for their livelihood, and the sector involves about 9 % of the labor force (Mazid 2002). The fisheries sector is a prominent socio-ecological system in many regions across the globe, and large numbers of people worldwide are dependent on fisheries for their livelihoods. The fundamental linkages between ecological and socioeconomic dynamics mean that it is essential to address climate-related concerns in a collaborative and interdisciplinary manner and for scientists and policy makers to adopt a holistic approach toward the ecological, economic, and social impacts of climate change. Science-based evidence can contribute to the improved design of adaptation policies for the fisheries sector that strike the right balance between livelihoods security and income generation. State-of-the-art technology such as satellite-based remote sensing has facilitated real-time monitoring of the properties of marine systems and driven advances in marine research; however, further efforts are required to improve the accuracy and precision of analyses of seasonal and annual trends. Data on marine ecosystem productivity in the BoB, i.e., on biomass measured as chlorophyll concentration, reveals a sharp decline within a time span of a decade. Biomass distribution affects the growth of fish, and there is a known relation between them. The next step is to work out how best to make use of this information in the process of discussion and formulation of adaptation measures.

Case Study 2: Multifunctional Agroecosystems and the Climate-Driven Transformation

Many scientists worldwide have attempted to analyze crop responses to weather/climate variability by employing a blend of computer generation simulations and experimental research (Porter and Semenov 1999). The significance of climate variables for agronomic studies is well recognized. For example, the thermal kinetic window for a crop variety is an important attribute of the climate that regulates plant metabolism and physiological activity (Mahan et al. 1987). For rice, there is little temperature effect on leaf carbon dioxide assimilation from 20 °C to 40 °C (Egeh et al. 1994). On the other hand, crop growth simulations show that rice yields decrease by 9 % for each 1 °C increase in seasonal average temperature above a certain threshold value (Kropff et al. 1993). This understanding informs the second case study, which explores the process of agricultural transitions that is associated with a decline in rice production in Wayanad, Kerala, South India. Demonstrated decline in the rice production (harvest in tonnes per unit hectare) shows a considerable degree of correlation to temperature variability and specifically to trends in diurnal temperature range (DTR) anomalies. Diurnal temperature range encapsulates daily temperature fluctuations; this is an interesting dimension of climate variability that apparently has significant effects of crop production (Welch et al. 2010), comparable to those of (more frequently studied) seasonal temperature variation (Jagadish et al. 2010).

Most studies relating crop productivity and climate variability focus on rainfall distribution and variance and its effects on plant growth. Few consider temperature variance, and, among these, only a handful selects fluctuations in temperature as the climate variable for analysis (Easterling et al. 1997). Likewise, scant attention is paid to DTR. Fan et al. (2011) define monthly mean DTR as the difference between the monthly means of maximum and minimum temperature values. There is debate about the nonlinear effects of DTR fluctuation on yields of different crop (Gallo et al. 1996). Nonetheless, most studies conclude that negative effects are sharply accentuated outside the optimal fluctuation range [OFR] for a particular crop type (Lobell et al. 2011). An International Rice Research Institute report examines the temperature sensitivity of the most widely grown (and high-yielding) rice variety in the tropics (IR64): when the daily maximum temperature rises from 28 °C to 37 °C, a 50 % drop in seed set is observed, while a further rise to 39 °C may result in the variety failing to produce any grains at all. In essence, temperature dynamics substantially govern the crop yield (Chen et al. 2004).

Wayanad, unlike the other parts of Kerala, has only two rice growing seasons: summer and winter (other regions also have a third crop, autumn rice, grown post-monsoon) (Fig. 4a). To represent crop production in these two seasons, the temporal trend of rice production is taken as surrogate. The climate data for analysis was procured from archives of the Indian Institute of Tropical Meteorology (IITM). The best available dataset, daily values of T_{max} and T_{min} for the Western region of India (which includes Wayanad), was used in order to calculate the mean monthly values. For analysis DTR anomaly, values for monthly mean T_{max} and T_{min} surface air temperature were analyzed using a linear regression equation. Figure 4b shows centennial (1903–2003) trends in DTR anomaly values [i.e., deviations from the mean] for the Western region of India (including Wayanad), segregated into seasonal trends: MAM (pre-monsoon/summer), JJA (monsoon), SON (post-monsoon), and DJF (winter). The figures also show intra-seasonal DTR variations. How should these trends be interpreted?

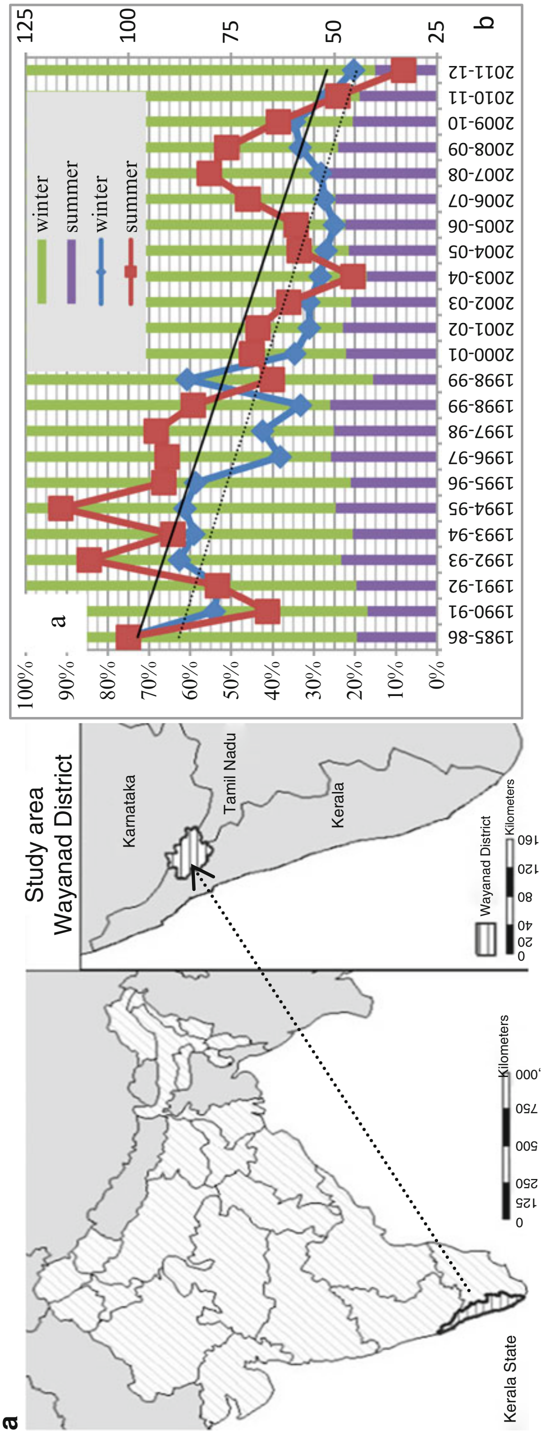

Fig. 4 (continued)

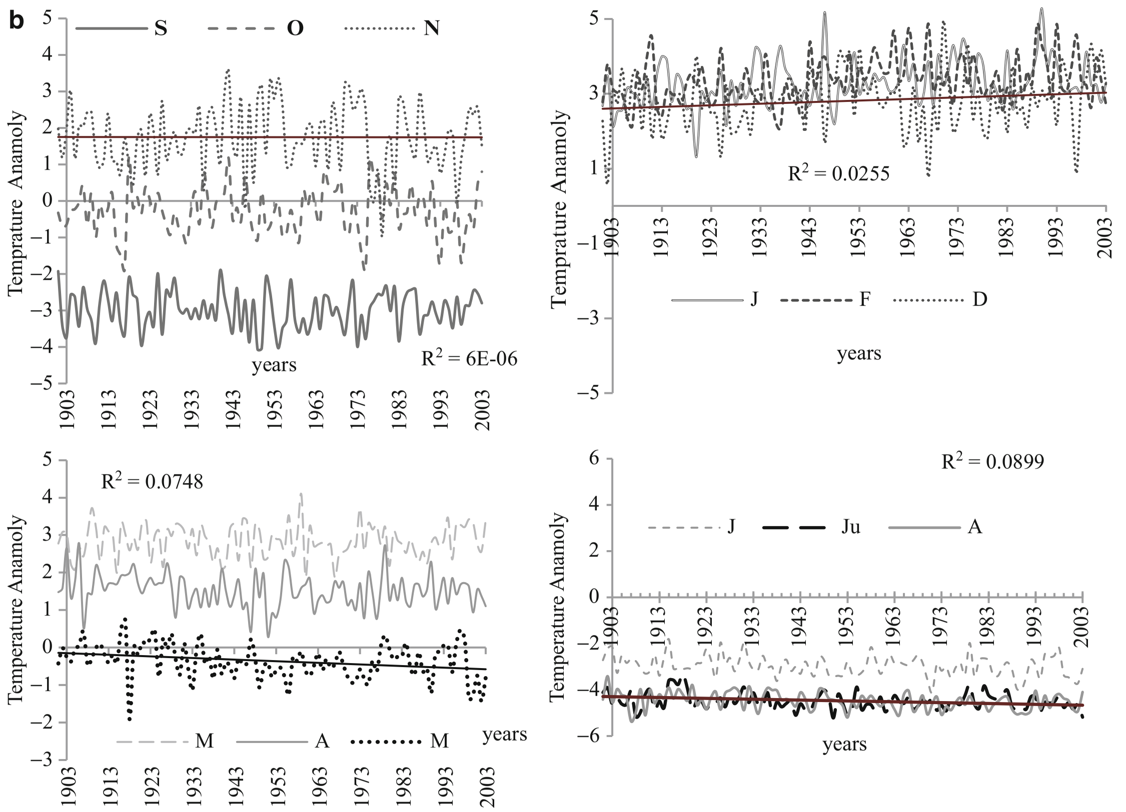

Fig. 4 Location of Wayanad agroecosystem. (**a**) Temporal trend in rice production for two seasons, summer and winter (% on base year 85–86 (*line*), and % on same year (*stacked columns*); (**b**) temporal trend of DTR anomalies for four temporal slices of annual calendar

For DJF, there is a clear positive anomaly, while in May the trend is negative (also in JJA and in early autumn in September). A negative anomaly is a possible indicator of escalating atmospheric warming (if increases in maximum temperature and accompanied by even larger increases in minimum temperatures, reducing the difference between day and nighttime temperatures). For any crop, and especially rice, which is sensitive to difference in day and nighttime temperature, even a small shift away from the optimal temperature range (induced by early warming, increased warming, a change in seasonal maximum temperature range, or reduced difference between day and nighttime temperature) can potentially affect the yield considerably (Jagadish et al. 2010). To examine this possibility, rice production in Wayanad is compared with the DTR trends for the region. Since winter rice is the main contributor to total rice production, a positive temperature anomaly during DJF can be considered to represent favorable conditions for maintaining the yield, while the intra-seasonal variability during MAM can be crucial in determining the harvest. This comparative analysis highlights how comparison of data from different sources can yield new insights, of practical value, into the vulnerability of socio-ecological systems. Specifically, DTR appears to be a useful variable for analysis of the possible influence of climate variability on crop production and its role as a driver of agricultural transformation.

Case Study 3: Climate-Induced Human Migration

This case study examines climate-induced human migration, which is acknowledged as a growing concern worldwide (Reuveny 2007). Regions that are particularly vulnerable to climate change include deltas and catchment areas, low-lying coastal zones, and small islands (Nicholls et al. 2007). Bangladesh is categorized as the region in Asia most vulnerable to climate change and as one of the most vulnerable in the world (IPCC 2007). In addition to classical economic migration (above 3 % of world population migrates annually for work), numerous reports comment on the alarming amount of environmentally induced migration, more recently in connection with climate change. The Stern Report (2006) states that 150–200 million people are likely to be displaced by climate change, while a dossier by Christian Aid (2007) states that the number could be as high as a billion. At a national level, the Internal Displacement Monitoring Center (IDMC) in Bangladesh categorizes one third of the total population as climatically vulnerable, likely to be confronted by the threat of displacement (Yonetani 2011).

The theoretical framework for this study of migration is taken from the Eurostat 2000 report that analyzes migration in terms of the interplay of push and pull factors (Fig. 5a). The concept of Internally Displaced People and Refugees has been adopted for assessing climate-driven migration patterns (Nagabhatla 2012). Drawing on a literature review, discussions with stakeholders and available data (formal and informal, local and national-BBS, 1994), a graphical representation of climate-induced migration in Bangladesh was produced (Fig. 5b). According to Akter (2009), climate-induced human mobility or migration of Bangladesh, driven by natural calamities and extreme events such as floods, droughts, and cyclones, displaces nearly 30 % of the total population each year. Present study, focusing

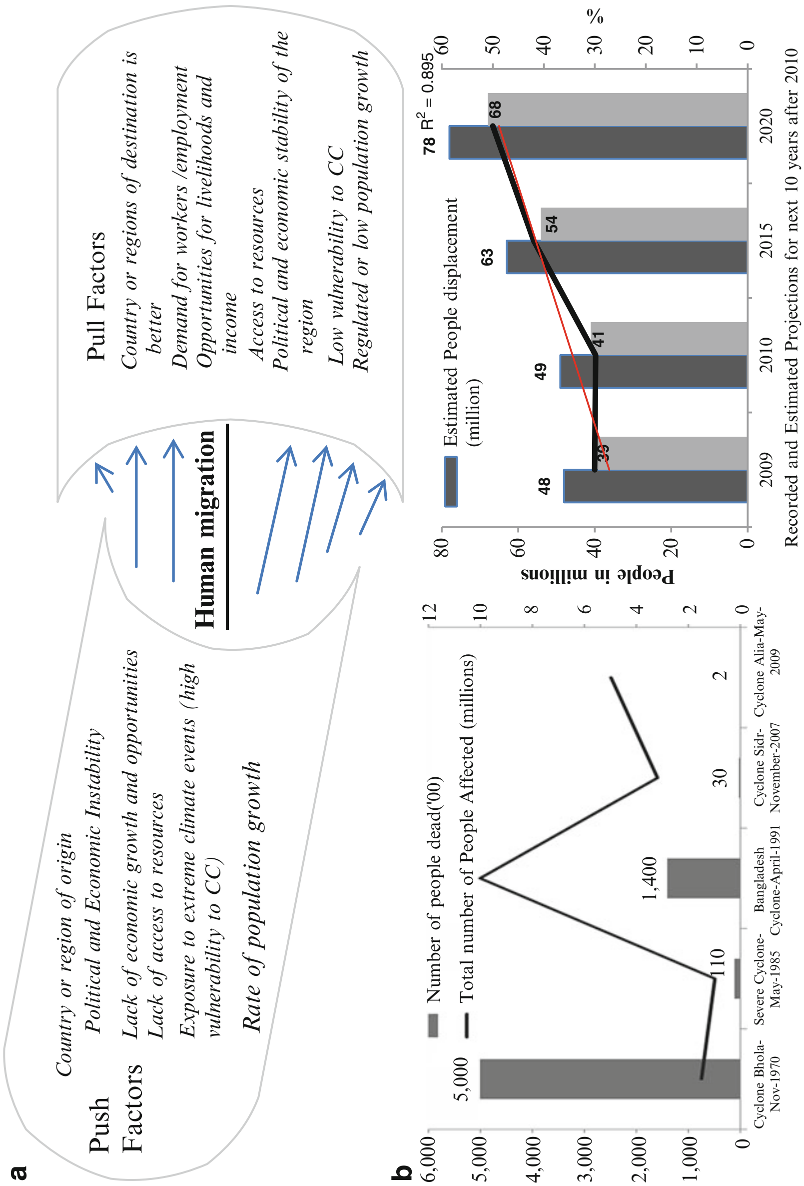

Fig. 5 (continued)

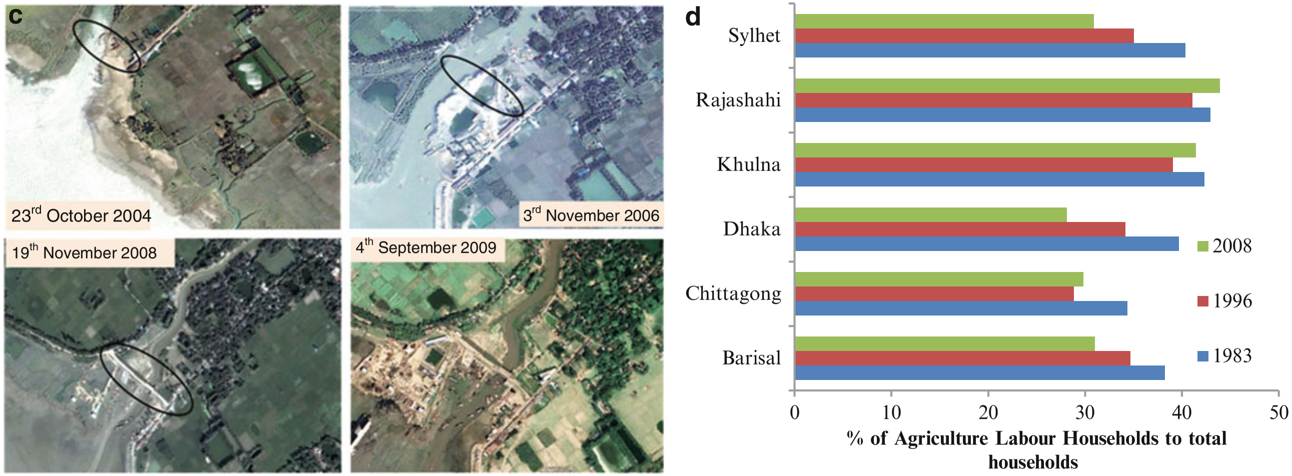

Fig. 5 Climate change vis-a-vis and human migration; (**a**) push and pull factors that are fundamental to drive human migration (Adopted from Eurostat 2000); (**b**) data assimilated from secondary sources for last four decades (1970–2010) and projection for future (refereed from available research) illustrate the intensity of crisis related to human displacement. (**c**) Visual representation of salt water intrusion in coastal Bangladesh that renders croplands unsuitable and pushes locals to migrate for work (Source: Google Earth archives); (**d**) agriculture labor as the selected social indicator at provincial level – an important factor in human migration study

on climate-related determinants of human migration, drew on the secondary data on migration available from various published records, anecdotal information, and the results of surveys by federal agencies. Information aggregation was subject to the common limitation that available data was at different timescales and for different administrative units. This made it difficult to gain an overall view of migration patterns.

At local level, socioeconomic information collected for districts (in Bangladesh, this is the local administrative level below province and state), on attributes such as the total number of households, the proportion of urban versus rural households, and the number of landless households, provided important baseline information for analyzing the impact of climate change and variability on human mobility. In common with most secondary data-based analysis, this synthesis was subject to two main limitations: (a) there were concerns about possible inaccuracies (over- or underestimations) in the data. (b) It was often difficult to separate the required set of information (e.g., for a particular scale of analysis or topic of interest) from the common data pool. For instance, data on human migration recorded by Bangladeshi authorities are national-level records in an aggregate format. So, it is difficult to separate out the human mobility caused by different drivers: economic, environmental, or climatic. A further aspect that was difficult to extract from national records was seasonality, which plays a huge role driving migration, especially climate-related migration.

The statistical analysis of disaster-induced displacement in Bangladesh shows that an average of 2 % of the total population, i.e., about three million people, is possibly affected by cyclones, 25 % (39 million) impacted by floods, 0.1 % (nearly 50,000) by river basin erosion, and about 3 % (5 million) by droughts (ADB 2011, 2005). A total of 26 major cyclonic events affected Bangladesh's costal region from 1970 to 2009; thus in this period, cyclones were almost an annual event. The major cyclones in 1970, 1985, 1991, 2007, and 2009 were the most distressing for human populations and caused the greatest loss of natural capital. Records of human fatalities and loss of assets indicate that the number of people affected is close to the number of people displaced (Fig. 5b). Floods stand out as the type of disaster that displace the largest number of people.

Furthermore, projections in this regard also are very concerning. The country is projected to experience massive environment-driven displacement, affecting in the order of 49, 63, and 78 million people in 2010, 2015, and 2020, respectively (Chowdhury et al. 2009). The alarming estimate that, by 2020, national-level human displacement could affect about half the total population of Bangladesh certainly calls for this issue to be given priority in the national policy agenda. Coastal zones with flat topography and thus maximal exposure to atmospheric and climatic fluctuations are the most vulnerable, as can be appreciated from the estimation that the number of people displaced in these regions will be several fold higher than in inland regions, particularly among the laboring classes. Figure 5c visual represents the condition of salt water intrusion in the coastal zone, the process that by and large impacts the surrounding agriculture landscape. To further explore this phenomenon, a set of socio-ecological indicators of

Table 1 Vulnerability assessment at provincial level in Bangladesh. This process was based on the selected indicators assisted by secondary data

Bangladesh	1(low)–5 (high)	1(low)–5 (high)	1(low)–5 (high)	1(low)–5 (high)
Provincial divisions	Exposure to extreme climate events	Sensitivity (poverty)	Adaptive capacity	Climate vulnerability
Barisal	4	4	2	5
Chittagong	4	3	2	4
Dhaka	2	1	4	2
Khulna	2	3	4	3
Rajshahi	1	5	5	1
Sylhet	5	1	1	4

national-level climate vulnerability was selected. The selected indicators were number of people displaced (taken from official records) as a social indicator (income of agricultural laborers households that are mostly landless is used as a surrogate, as shown in Fig. 5d), poverty as the indicator of the economic situation or economic indicator and the degree of exposure of a resource systems to disasters as an ecological indicator (for details of other indicators, not shown, see Nagabhatla 2012).

Numerical data on above indicators was compared with climatological data at national and district level. Results showed that Rajshahi region had the second highest proportion of landless households (27 %), after Dhaka, the capital city. Nevertheless, evaluation of the whole indicator set at districts level showed that Barisal was the most vulnerable region (Table 1). A study by Chowdhury et al. (2009) is in agreement with current results and also provides information on migration routes. The principal migration flow is from coastal zones to inland areas (up to 200 km inland). In addition, migration from rural to urban zones and from one livelihood sector to another (e.g., from fisheries to industrial labor) is another important dimension. The growth of crowdsourcing in the research and development field opens up opportunities to feed qualitative information and stakeholder perceptions into the integrated decision support systems (Wells 2013). Overall, there is clearly a link between the increase in numbers of internally displaced people and climate dynamics, although more evidence is required on the role of climate change as a driver of long-distance migration, i.e., to show that the term "climate refugees" corresponds to a real phenomenon.

Changes in climate and weather patterns provoke migration not only within a country but also across national borders. This topic has still not received much attention in climate debates and policy. A further difficulty noted by Chellaney (2007) is the lack of clarity on the fundamental nature of human migration, particularly with respect to refugees, including climate refugees. Migration is inherently a transboundary concern and demands a cross-country dialogue and perhaps ratification of migration-specific multilateral agreements. Development interventions, decision-making, and environmental and climate policy on these critical issues and related ones need to be grounded in scientific evidence and ground-level knowledge. Improved accuracy in the forecast and prediction of climate trends and events is a key way the scientific community can contribute to efforts to tackle the issue of migration.

Conclusion

Climate adaption and management is an ambitious task. Data constraints are often mentioned as a factor that hinders integration of climate information in decision-making (Nagabhatla et al. 2012). While the ongoing need to address climate-related uncertainties is apparent, management policies for natural resource governance have not yet been able to satisfactorily factor in the existing and anticipated complexity associated with climate variability and change. For instance, lack of progress in downscaling climate information to fit local requirements is still a matter of concern (Hewitson and Crane 2006), especially since downscaling is crucial for understanding local scale coping strategies and addressing grassroots level problems such as livelihoods and food security. Studies that contribute toward functional knowledge of the complexity that is inherent of climate processes can play an instrumental role in laying the foundations for effective adaptation planning. The two modules of this chapter aim to make a contribution in this regard.

The core of the chapter is the structural weave of the two key modules (CCM and CCA) that (a) elucidates the multilevel interactions within and across different socio-ecological systems, while advocating a transdisciplinary approach; (b) provides an empirical demonstration of the application of real-time climate information covering a range of scales from national to local; and (c) illustrates the multifaceted nature of climate data analysis and its potential to shed light on multiple patterns and trends at inter-seasonal, interannual, annual, decadal, and longer timescales. Clearly these issues – separately and together – are highly relevant for short- and long-term strategic planning for adaptation.

The CCM module highlights how scientifically derived climate information can help to unfold the layers of uncertainty surrounding the impacts of climate change. In fact, scientific observation, monitoring, and modeling have already contributed greatly toward preparation of climate coping strategies (Rozum and Carr 2013). Voices from the scientific community (e.g., FAO 2008), the grass roots (field notes), and the media (Economic Times 2013) coincide in warning that that the long-term impact of climate variability and change may lead to a state of crisis, most likely related to food and water insecurity. Taking heed of these warnings, adaptation planning in multiple sectors, including agriculture, water management, business, development, and conservation, must go hand in hand. Cross-sectoral planning can benefit hugely from application-ready forecast and hindcast climate products, for example, MME. The forecast simulation (using hindcast data) for the Indian region shows a fairly good level of agreement with the observation data, indicating the potential for model-based forecast prediction. MME forecasts captured overall trends of annual and seasonal rainfall; however, events such as floods and extreme anomalies in annual rainfall were not captured with a high degree of confidence. Likewise, tropical monsoon forecasting remains a perplexing task for climate experts (Goswami and Krishnan 2013). In summary, the outputs of climate modeling can be of practical application for adaptation planning if input variables in climate models are set for specific applications (i.e., by customizing application-specific ensembles).

Dialogue on climate change involves experts from varied sectors such as energy, sociology, finance, trade, ecology, economics, and politics, who often ask for projections of possible climate-related impacts on their respective domains of interest. However, it is rare that experts from these different disciplines come together to work on a common domain of interest. Transdisciplinary collaboration has the potential to detect complementarities in adaptation requirements across varied socio-ecological systems. From this perspective, the second module of the chapter provides examples of how climate data can be used as a frame of reference by a range of stakeholders to assist adaptation planning, for example, in the context of case study from Bangladesh, by planning climate smart agriculture that secures livelihoods not just for land owners but also for agriculture laborers, can indirectly mitigate climate-induced human migration.

Additionally, the CCA module highlights the importance of understanding climate interactions in varied social, economic, and environmental contexts and at different scales and for different seasons and regions. The selected case studies demonstrate the application of climate information to three subsystems. The first case study clearly demonstrates the declining productivity of marine fisheries in Bangladesh over the last three decades. One might assume that state-of-the-art technology and fishing gear would have helped alleviate the problems of the marine fish industry and associated livelihoods. However, two factors are crucial: firstly, technology enabled overharvesting of fish resources; secondly, the combined impact of overharvesting and ocean-land-atmosphere dynamics (i.e., local-level climate dynamics) has depressed marine ecosystem productivity. Integration of climate attributes into a reanalysis of the causes of changes in productivity is an example of a synoptic calibration of climate data for sector specific study. This sort of calibration is crucial in order to project long-term impacts on food and livelihood security in the region. In-depth examination of the seasonal and temporal correlation between marine fish productivity and climate variability expressed in terms of changes in chlorophyll, SST, and SSH provides new insights into the problem of declining biomass in marine systems.

The case of agroecosystem in Wayanad in Kerala is a very typical example of local-level analysis. This case study examines how climatological changes alter seasonal temperature patterns that in turn affect crop physiology, potentially disrupting the cycle of regular growth and reducing crop productivity. Productivity is, in turn, a key factor in decision-making on crop selection at the farm level. Transformation in the agroecosystem, specifically a market-driven shift from conventional food crop varieties (in Wayanad, rainfed rice) to more high-value products such as banana, coffee, and areca nut, may have contributed to incomes and the economic stability of landowners. However, the same transformation threatens agrobiodiversity and the livelihoods of agriculture laborers (Nagabhatla and Kumar 2013).

Statistical analysis of temperature variation and rice yield for Wayanad highlights the possible impact of changes in DTR on crop phenology and physiology, as also reported by Wassmann et al. (2009).

The case study of human migration in Bangladesh illustrates the pressing need for appropriate action on climate-driven human mobility. The theory of migration has faced continuous critical review and criticism of the failure to make a clear differentiation between internally displaced people and refugees. A review of literature from Bangladesh indicated that there has been an increase in seasonal migration from 20 % to 45 % and in permanent migration from 2 %to 8 % over the last decade. Much of the increase can be attributed to the more frequent occurrence of extreme climate events, mainly associated with monsoonal anomalies. An early warning system and improved accuracy of forecast information could help address the problem (Nagabhatla 2012). Fisheries and migration is representative of the diversity of socio-ecological systems in the climatically sensitive region of Bangladesh. Empirical experiments similar to those carried out in the present study applied to agriculture, inland fisheries, forestry, and other sectors would be required to provide the overall view necessary to the design integrated approaches for effective adaptation planning.

The CCA module provides further evidence of the need for cross-/ transdisciplinary approaches to assess and address the impact of climate change and in planning adaptation measures for complex socio-ecological systems. While scientific data and models generate strategic knowledge and thus provide key inputs for smart policies for climate change adaptation, a culture of collaboration, partnerships, and exchange of knowledge between the scientific world, local communities, business, and the governance bodies is a prerequisite for adaptation and positive social transformation in response to the challenge of climate change. The analysis presented in this chapter has benefited immensely from collaboration and partnership between the researchers and Asia Pacific Climate Center, an institute with a long-term vision of building capacity for the application of climate information to meet societal needs. The use of climate data for societal well-being will not address all climate-related uncertainties or mitigate all the negative consequences of climate change; nevertheless, it can make a sizeable contribution toward carving a knowledge pathway to respond to and cope with climate change. The key challenge is to set in motion social learning processes that assimilate the multiple dimensions of climate change and its impacts. The analyses and case studies presented in this chapter highlight the potential of climate data, both forecasted and observed, to contribute to social learning. The improved availability, accessibility, and accuracy of data open up new frontiers for transdisciplinary understanding of the uneven impacts of climate change on socio-ecological systems at global, regional, and local scales.

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Urbanization and Climate Change

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Abstract

Urbanization has profoundly affected the environment and climate all over the world and has intensified the climate change impacts. The aim of this research is to study of effects of urbanization as the most suspicious factor of climate change in a holistic view applying system dynamics approach. An introduction to urbanization and climate change as an obstacle to sustainable development will be presented in general. Then, in particular, Tehran metropolis is described, since the city is an excellent example of the issue. In this regard, the focus will be on complexity of such dilemma. Then, system dynamics approach (SDA) that can play a key role in solving these kinds of problems will be introduced. Furthermore, the prototypes of the system are recognized. Finally, management practices and solutions of the problem are presented. The effects of urbanization will be reviewed in a new approach which has not been applied in previous studies. The involving mechanisms in this process are recognized. "Fixes that fail," "success to the successful," and "tragedy of commons" are the most prevalent prototypes in the system based on which solutions are presented.

Keywords

Climate change • Urbanization • Tehran • Iran • System dynamics

Introduction

The Intergovernmental Panel on Climate Change (IPCC), the leading international body for the assessment of climate change established by the United Nations Environment Program and the World Meteorological Organization in 1988, indicates that there is "high confidence" in the scientific community that anthropogenic climate change is contributing to sea-level rise and consequent high-risk scenarios for coastal cities without proper infrastructure (IPCC 2007a).

Climate change is undoubtedly a global problem, one that becomes more challenging over time as it continues and more people move to cities. Most affected by climate impacts and climate-induced migration are highly vulnerable cities, notably megacities in developing and, to a lesser degree, emerging market countries where the physical, social, and regulatory infrastructures are typically insufficient to address these emergent stresses (DePaul 2012).

Research on the intersection of climate change and migration and their combined impact on megacities is still in its infancy and hence insufficient in the face of critical policy questions on the subjects of mitigating climate change and building resilience to impacts. Scholars, such as De Sherbinin et al. (2007), Campbell-Lendrum and Corvalan (2007), Khan et al. (2011), and Bambrick et al. (2011), assess the health and social impacts of climate change on cities and megacities, broadly concluding that climate change should be seen as a significant issue for cities, and policies at all levels of government need to be designed to reflect this.

Ahmed (2009), Tacoli (2009), and Ranger et al. (2011) studied migration patterns and climate-induced urbanization in developing and emerging market countries. Their studies suggest that physical and social infrastructure currently cannot cope with mass urbanization. These scholars neglect to consider the stresses that climate change will impose on overpopulated regions. Only Adamo (2010) considers the interrelation of migration, climate change, and cities, though she investigated theoretical implications rather than evaluating specific national and regional policies. Institutions, like the United Nations Population Fund, conduct extensive research on trends in population, climate change, and urban density (Dodman 2009), but the connection to migration is seldom made.

In order to assess the coinciding effects of climate change and climate-induced migration on megacities, DePaul (2012) outlined a typology of climate migrants and refugees by considering the impacts of climate change as multipliers to current push factors of migration. Then, he analyzed the stresses that climate change imposes on megacities, particularly the dual stresses of mass urbanization and increasing climate vulnerability, and he utilized a case-specific analysis of the interconnectedness of developing and emerging market countries such as Bangladesh to illustrate the forces that drive involuntary international and intranational mobility from rural to urban settings and the subsequent stresses megacities experience and will continue to experience in upcoming decades. All in All, the problem at hand is undoubtedly global and so systemic change is necessary. In particular, Tehran metropolis is exposed to chronic situation of pollution as a result of rapid development as well as mismanagement. The study of Tehran City climate change and urbanization and applying system dynamics are the research innovations. The ability of system dynamics has been approved in the other studies in solving such complex issues; the effect of urbanization on climate change will be reviewed in this new approach, and the old approach in managing climate change will be replaced by the new strategies in confronting with climate change.

System Dynamics Approach, an Efficient Tool in Confronting with Such Complex Problems

System dynamics approach (SDA) is a branch of systems thinking which provides a simulation tool to model feedback relations in a system. In this approach, taking care of interactions among the elements, systems are considered as closed systems with feedbacks from outputs to inputs (Bagheri 2006; Hjorth and Bagheri 2006). It is a useful tool to study the trends of changes and their causes, to understand the physical processes and the flow of information, and to design and simulate the consequences of policies in a system. The interactions of system elements make its "structure" which is responsible for the system behavior (Vlachos et al. 2007).

Focusing on controls, feedbacks, and delays, SDA is a modeling approach used for studying and simulating complex systems while emphasizing on policy analysis and design. The relationships between system components as well as feedbacks affecting system regulations are depicted in causal loop diagrams (CLDs). Based on the positive and negative impacts of variables on each other, feedback loops can be reinforcing or balancing (Bazrkar and Eslamian 2013).

Climate change, particularly in an urban watershed like Tehran which is experiencing rapid development, is an excellent example of a system with dynamic complexity. This is a feedback system with many complex parts and vast amounts of data. Thanks to SDA, integrated management of the basin has been studied in many basins and performed well and proved to be an excellent tool to assess and manage water resources in the basin (Madani and Marino 2009; Sanchez-Roman et al. 2009). An excellent source of theoretical and practical evolution of system dynamics is available in Winz et al. (2009). In researches that have been done in the field of global warming, several approaches were applied that most of them neglect or, to some extent, pay low attention to other factors such as social, economic, and cultural impacts. All in all, system dynamics approach (SDA) application for solving such problems has not been applied yet. Furthermore, although the ability of SDA in modeling such complex issues has been proved, it is not applied in climate change adaptation and mitigation. In addition, lack of socioeconomic dimension of the previously used model to generate sustainable strategies throughout the basin is apparent. Therefore, as mentioned above, it is very important to consider socioeconomic aspects of the system in order to model the global warming for achieving a sustainable situation in decision-making. In this chapter, SDA has been applied in order to study climate change process and drivers in a holistic view.

Ten archetypes are generally acknowledged as forming the set of tools that reveal patterns of behavior in systems: limits to growth, shifting the burden, eroding goals, escalation, success to the successful, tragedy of the commons, fixes that fail, growth and underinvestment, accidental adversaries, and attractiveness principle. Each of the archetypes will be illustrated and discussed, along with general guidelines, prescriptive actions, and a set of seven steps that are useful for applying the archetypes for successful managerial interventions.

Dynamic Hypotheses

Observations about system relationships, operations, and patterns that are extracted from observed data are the two bases for the SD method of determining which feedback loops dominate in creating the time patterns. Since the real system usually contains a great number of loops, many of which do not directly create the important patterns; the analyst must eliminate many of the nondominant loops and variables. There is no algorithmic way to do this. It requires informed judgment that arises from long experience in studying systems to conceptualize this

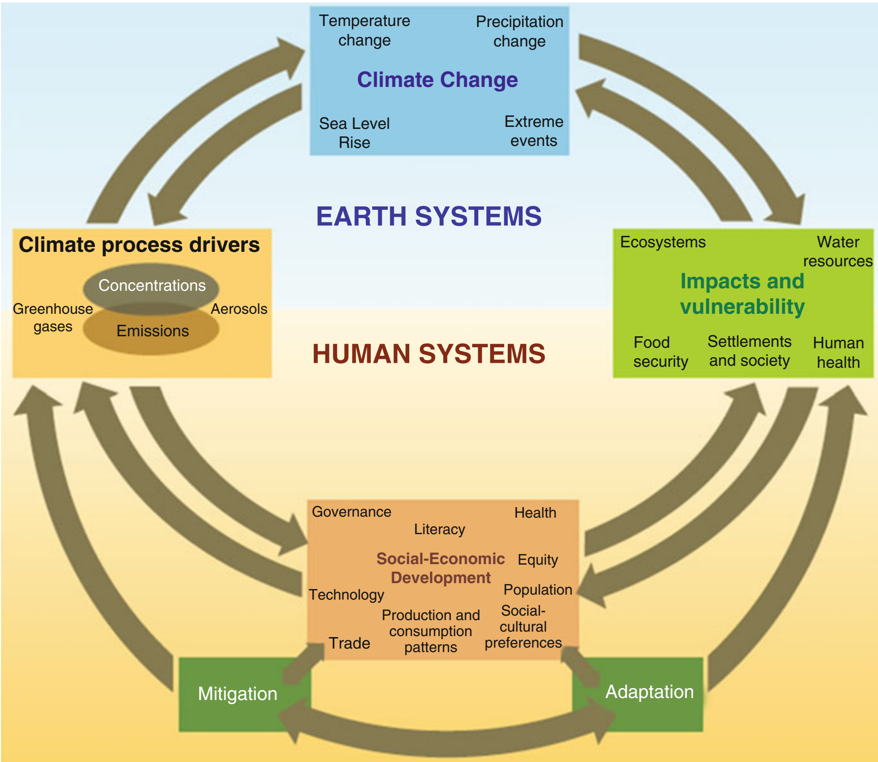


Fig. 1 Schematic framework representing anthropogenic drivers and impacts of and responses to climate change and their linkage (IPCC 2007c)

hypothetical dominant system. Since such judgments are sometimes in error, a procedure has been developed to test the judgment. The analyst's mental model of the dominant loop structure and how it creates the important time patterns is described in detail in writing. This written description is called the Dynamic Hypothesis (Fey et al. 2004). In this chapter, drivers of climate change in the study area will be discussed.

Cities are increasingly vulnerable to climate impacts because of "coastal location, exposure to the urban heat-island effect, high levels of outdoor and indoor pollution, high population density, and poor sanitation" (Campbell-Lendrum and Corvalan 2007). These concurring trends have resulted in unprecedented pressure on megacities (Fig. 1).

Climate Change

Weather and climate have a profound influence on life on Earth. Many consider the prospect of human-induced climate change as a matter of concern. The IPCC

Second Assessment Report (IPCC 1996) (hereafter SAR) presented scientific evidence that human activities may already be influencing the climate. It is necessary to understand the climatic system for assessing and determining human influence on climate led to climate change.

Since the notions "weather" and "climate," in common parlance, are loosely defined, firstly, these two notions will be clearly described.

The "weather," as we experience it, is the fluctuating state of the atmosphere around us, characterized by the temperature, wind, precipitation, clouds, and other weather elements. This weather is the result of rapidly developing and decaying weather systems such as mid-latitude low- and high-pressure systems with their associated frontal zones, showers, and tropical cyclones. Weather has only limited predictability.

"Climate" refers to the average weather in terms of the mean and its variability over a certain time span and a certain area. Classical climatology provides a classification and description of the various climate regimes found on Earth. Climate varies from place to place, depending on latitude, distance to the sea, vegetation, presence or absence of mountains, or other geographical factors.

Statistically significant variations of the mean state of the climate or of its variability, typically persisting for decades or longer, are referred to as "climate change." The Glossary gives definitions of these important and central notions of "climate variability" and "climate change."

Climate variations and change, caused by external forcings, may be partly predictable, particularly on the larger, continental and global, spatial scales. Because human activities, such as the emission of greenhouse gases or land-use change, do result in external forcing, it is believed that the large-scale aspects of human-induced climate change are also partly predictable. However the ability to actually do so is limited because we cannot accurately predict population change, economic change, technological development, and other relevant characteristics of future human activity. In practice, therefore, one has to rely on carefully constructed scenarios of human behavior and determine climate projections on the basis of such scenarios.

The traditional knowledge of weather and climate focuses on those variables that affect daily life most directly: average, maximum and minimum temperature, wind near the surface of the Earth, precipitation in its various forms, humidity, cloud type and amount, and solar radiation. These are the variables observed hourly by a large number of weather stations around the globe. However, this is only part of the reality that determines weather and climate. The growth, movement, and decay of weather systems depend also on the vertical structure of the atmosphere, the influence of the underlying land and sea, and many other factors not directly experienced by human beings. Climate is determined by the atmospheric circulation and by its interactions with the large-scale ocean currents and the land with its features such as albedo, vegetation, and soil moisture. The climate of the Earth as a whole depends on factors that influence the radiative balance, for example, the atmospheric composition, solar radiation, or volcanic eruptions. To understand the climate of our planet Earth and its variations and to understand and possibly predict the changes of the climate brought about by human activities, one cannot ignore any of these many factors and components that determine the climate. We must understand the *climate system*, the complicated system consisting of various components, including the dynamics and composition of the atmosphere, the ocean, the ice and snow cover, the land surface and its features, the many mutual interactions between them, and the large variety of physical, chemical, and biological processes taking place in and among these components. “Climate” in a wider sense refers to the state of the climate system as a whole, including a statistical description of its variations.

Some extreme weather events have changed in frequency and or intensity over the last 50 years.

It is very likely that cold days, cold nights, and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. It is likely that heat waves have become more frequent over most land areas. It is likely that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas. It is likely that the incidence of extreme high sea level has increased at a broad range of sites worldwide since 1975.

Temperature Change

Eleven of the last 12 years (1995–2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906–2005) of 0.74 [0.56–0.92]°C is larger than the corresponding trend of 0.6 [0.4–0.8]°C (1901–2000) given in the average Arctic temperature (TAR). The linear warming trend over the 50 years from 1956 to 2005 (0.13 [0.10–0.16]°C per decade) is nearly twice that for the 100 years from 1906 to 2005.

The temperature increase is widespread over the globe and is greater at higher northern latitudes. Average Arctic temperatures have increased at almost twice the global average rate in the past 100 years. Land regions have warmed faster than the oceans. Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been taking up over 80 % of the heat being added to the climate system. New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates similar to those observed in surface temperature (IPCC 2007b).

Precipitation Change

Trends from 1900 to 2005 have been observed in precipitation amount in many large regions. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe, and northern and central Asia, whereas precipitation declined in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia. Globally, the area affected by drought has likely increased since the 1970s (IPCC 2007b).

Sea-Level Rise

According to IPCC, coastal areas are projected to be “exposed to increasing risks, including coastal erosion, due to climate change and sea level rise. The effect will be exacerbated by increasing human-induced pressures on coastal areas”

(Parry et al. 2007). Estimates for sea-level rise vary from 18 to 59 cm up to the end of the twenty-first century, this along with predicted changes in the frequency and/or intensity of storms, associated surges, and other extremes. Sea-level rise refers to the increase in the mean level of the oceans.

Sea-level rise and its associated impacts will, by the 2080s, affect five times as many coastal residents as they did in 1990. Tropical cyclone sand extratropical storms have been increasing in intensity since the 1970s.

Extreme Events

Ranger et al. (2011) argue that "many of the world's cities are hotspots of risk from extreme weather events and levels of risks in many cities are likely to grow due to a combination of population growth and development and rising intensities of extreme weather events."

Heavy precipitation events are defined as the percentage of days with precipitation that exceeds some fixed or regional threshold compared to an average "reference period of precipitation from 1961 to 1990." On average, observations indicate that heavy 1-day and heavy multiday precipitation events have increased globally throughout the twentieth century, and these trends are very likely to continue throughout the twenty-first century. Deviations from average weather patterns have been observed globally, with an increase in the frequency of heavy precipitation events in most areas of the world.

Flood

Floods are already one of the most frequent natural disasters often overwhelming the physical infrastructure, human resilience, and social organization of Dhaka, Mumbai, Jakarta, Caracas, and many other cities around the world. Some of these disasters are reported in the news and form part of the official statistics generated by national governments and international organizations. Yet for every flood large enough to get noticed internationally, there are hundreds that do not get reported, but kill and seriously injure many people and destroy or damage many people's homes and assets (Satterthwaite et al. 2007).

Floods are among the most costly and damaging disasters posing a critical problem to city planners as they increase in frequency and severity. The frequency and severity of flooding have generally increased during the last decade (compared to 1950–1980 flood data), along with the frequency of floods that exceed levels that only typically occur once every 100 years.

Drought

Drought can be defined as a phenomenon in which precipitation is significantly below normal levels, which leads to hydrological imbalances that negatively affect land resources and production systems.

Droughts have diverse implications for urban water systems and especially for the urban poor: they constrain water availability, and they might result, through complex causal chains, in infectious diseases, respiratory diseases, and other health problems. For instance, the drought affecting the western and central part of the

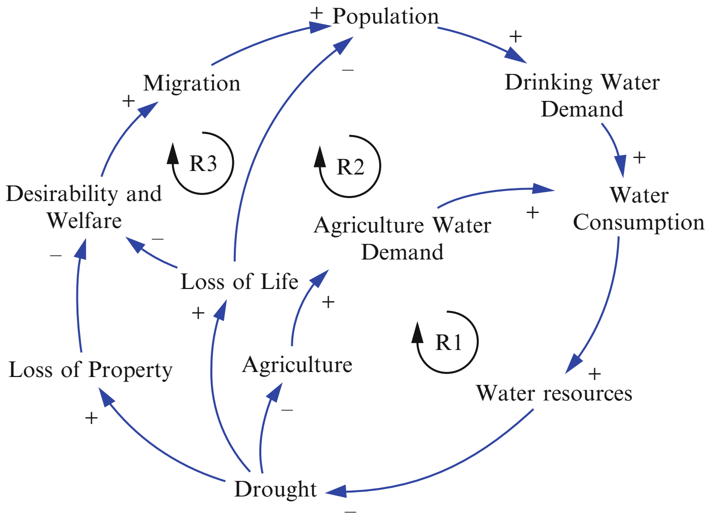


Fig. 2 Three reinforce loops

Amazon region, especially Bolivia, Peru, and Brazil in 2005, resulted in waterborne infections due to low water levels leading to pathogen concentration in surface water. There were also respiratory problems due to heavy smoke from forest fires (Confalonieri and Menne et al. 2007).

The CLDs in Fig. 2 show the interaction between climate drivers on water system. A “+” sign represents that an increase in the variable at arrow tail causes an increase in the arrowhead variable and indicates a reinforcing relationship between two variables. A “–” sign indicates a balancing relationship between two variables at the ends of an arrow and represents one variable that adversely affects the other.

The R sign shows reinforce loop, which means the governing mechanism will continue until the resource will be completely depleted or an inhibitor will stop the governing mechanism.

Climate Process Drivers

Greenhouse Gases

Greenhouse gas (GHG) emissions from commercial and residential buildings are closely associated with emissions from electricity use, space heating and cooling. The type of fuel used for heating and cooling also determines the amount of GHGs emitted. Larger houses consume more energy for heating and cooling.

Globally, 19 % of GHG emissions are associated with industrial activities. Although most cities in North America and Europe emerged and developed as a result of industrial activities, and still require industries to provide jobs and revenue, these same activities generate pollution.

GHG emissions from waste are relatively low in many urban areas in developed countries.

Global urban trends toward suburbanization mean that cities are sprawling and encroaching on land that may previously have been covered with vegetation – thereby reducing its potential to absorb CO_2.

Per capita CO_2 emissions vary from less than 1 t per year for Bangladesh and Burkina Faso to more than 20 t for Canada, the USA, and Australia.

The high concentrations of people and economic activities in urban areas can lead to economies of scale, proximity, and agglomeration – all of which can have a positive impact upon energy use and associated emissions.

The Urban Economy

The types of economic activities that take place within urban areas also influence GHG emissions. Extractive activities (such as mining and lumbering) and energy-intensive manufacturing are obviously associated with higher levels of emissions – especially when the energy for these is supplied from fossil fuels. However, there are fewer of these activities in many cities in developed countries, as lower transportation costs and the lower cost of labor elsewhere have encouraged industries to relocate elsewhere. In London, for example, industrial emissions halved between 1990 and 2006, as industrial activity has relocated to other parts of the UK or overseas (Fig. 3).

Air Pollution and Aerosols

Air pollution practically has the same effects on urban albedo as increased cloud cover. Through increased scattering and absorption in the atmosphere, less short-wave radiation reaches the surface reducing the impact of urban surface albedo. Alpert and Kishcha (2008), for example, show that urban areas (defined as areas with a population density of $\geq$400 people per km^2) received 8 % less solar radiation than rural areas between 1964 and 1989. Also, a little more radiation may be reflected back, slightly increasing the albedo of the Earth-atmosphere system as a whole, and of all the surface albedo values, water has the potentially lowest. Thus, it is not very hard to image, and for most people to remember from personal observations, that surfaces have a lower albedo and appear darker when moist. Although few studies have been done on the relation between albedo and soil moisture content (Wang et al. 2005), those that do seem to agree that moisture reduces the albedo up to at most ~0.08. On a degraded grassland site and a cropland (corn mixed with sunflower) site with sandy soils in northeastern China, Liu et al. (2008) measured the diurnal variability of surface albedo with data from 2003 to 2005. They examined the relation of albedo to soil moisture and solar elevation angle and found a negative exponential relationship. The albedo falls rapidly with the addition of soil moisture measured 5 cm below the surface, up to approximately 0.15–0.2 m^3/m^3 after which it stabilizes at an average albedo reduction of around 0.05–0.08. A case example of a real rainfall event showed a reduction of ~0.02, which may be an indication of a more usual situation.

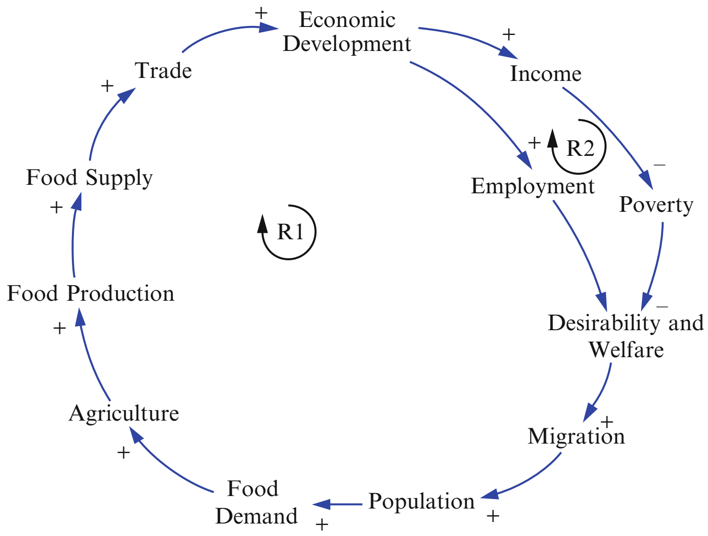


Fig. 3 Urban economy

Wang et al. (2005) also found a negative exponential relationship between surface albedo and soil moisture, with a reduction of more than 0.07 approaching stabilization. While stabilization occurred at a much higher soil moisture content, $>0.6\ m^3/m^3$, this difference may be explained by the more shallow measurement depth of 3 cm or the different soil characteristics of the semidesert to desert area of Gaize on the Tibetan Plateau.

Impact and Vulnerability

Ecosystems

Natural environmental processes provide benefits that are vital to city function and human health. These ecosystem services include oxygen production, carbon storage, natural filtering of toxins and pollutants, and protection of coastal societies from flooding and wind during storms.

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic, with an average decrease in surface pH of 0.1 unit.

Water Resources

Adamo (2010) discussed an example in northeastern Brazil where "regional rural–urban migration and urban growth have also been related to the negative effects of droughts in agriculture, while growing populations in cities generate a concentrated demand for water that surpasses local availability."

The availability, treatment, and distribution of water could be affected by climate change as temperatures increase and precipitation patterns change.

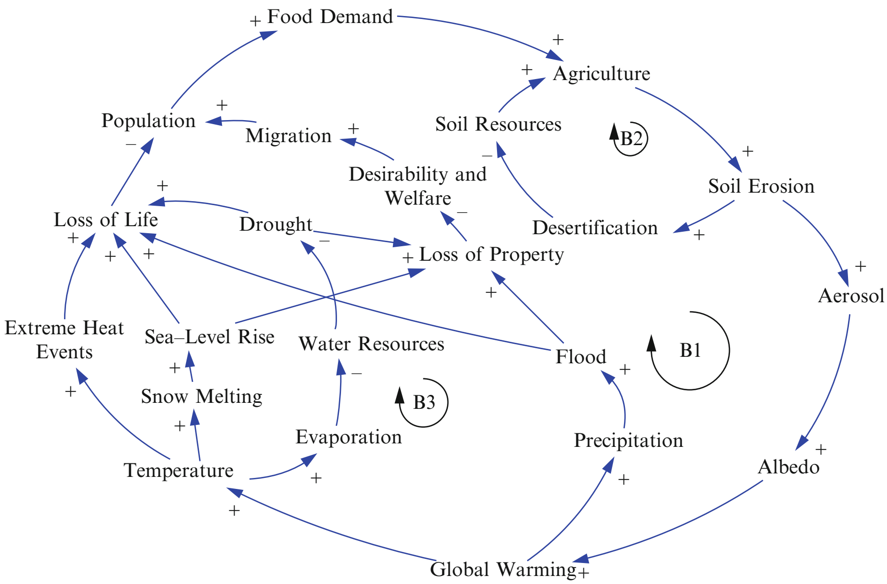


Fig. 4 Food security

According to IPCC (2007b), runoff and water availability are projected to have a regionally differentiated behavior by 2050: increases by 10–20 % at higher latitudes and in some areas in the wet tropics (e.g., populous areas in tropical east and southeast Asia) and decreases by 10–30 % over areas in the mid-latitudes and dry tropics, some of which are presently water-stressed. Increases in the frequency and severity of floods and droughts as well as declines in water quantities stored in glaciers and snow cover are also expected.

Food Security

The most important part of this system, which is affected by climate change, and consequently, water resources decrease, is food. B depicts a balancing loop, which will be balanced by the governing mechanism (Fig. 4).

Settlements and Society

Costs and benefits of climate change for industry, settlement, and society will vary widely by location and scale. In the aggregate, however, net effects will tend to be more negative the larger the change in climate. The most vulnerable industries, settlements, and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources, and those in areas prone to extreme weather events, especially where rapid urbanization is occurring (IPCC 2007c).

Human Health

A range of health-related risks is expected to arise from climate change, besides the physical hazards from floods (Confalonieri et al. 2007). It is expected that heat stress and respiratory distress from extreme temperatures will coalesce as air quality decreases. Waterborne and vector-borne diseases will result from changes in temperature, precipitation, and/or humidity. Less direct risks are expected as well as climate change negatively affecting livelihoods, food supplies, or access to water and other natural resources.

Mitigation and Adaptation

Climate change is a global challenge and needs to be addressed with global solutions. Climate change presents unique challenges for urban areas and their growing populations.

Near-term adaptation and mitigation analyses can be matched to conventional planning time scales, can explore opportunities and constraints given institutional and technological inertia, and can play an important role in integrating climate change considerations into other areas of management and policy (IPCC 2007c). Adaptation involves helping their constituents to cope with and adjust to any changes in their climate regime or natural resource base. This might involve targeted poverty reduction, asset building, early warning planning, and disaster response planning. Mitigation involves helping their constituents to reduce their GHG emissions. This might involve forest management or energy conservation interventions

Socioeconomic Development

Transportation Systems

Climate change impacts frequently disrupt transportation systems through weather conditions that have immediate consequences for travel and damage, causing lasting service interruptions.

By their very nature, cities are the center of high demand for energy and related resources. Climate change is likely to affect both energy demand and supply. The combination of urban population growth, changing local weather conditions, urban heat-island impacts, and economic growth has the potential to substantially increase demand for energy.

The increasing frequency and intensity of extreme climatic events and slow-onset changes will increase the vulnerability of urban economic assets and, subsequently, the costs of doing business.

Climate change will affect a broad range of economic activities, including trade, manufacturing, transport, energy supply and demand, mining, construction and related informal production activities, communications, real estate, and business activities.

Nick Mabey (2009) assesses that "these 'worst-case scenarios' are not low probability, but largely inevitable under current momentum of economic behavior."

The use of insurance as a means of spreading and reducing the losses from climate-related events has received increased attention (IPCC 2001; Wilbanks et al. 2007). New insurance mechanisms can be designed to help better distribute losses, for example, expanded property insurance coverage. Insurance can also work as agent of adaptation through incentives for risk reduction strategies, including better building codes and flood prevention schemes.

Substantial damage to residential and commercial structures is expected with the increasing occurrence of climate change-related hazards and disasters. In this regard, flooding is one of the most costly and destructive natural hazards and, as indicated earlier, one that is likely to increase in many regions of the world as precipitation intensity increases.

Health

Extreme climate events can disrupt the ability of individuals and households in urban areas to sustain livelihoods. Climate change-related disasters destroy livelihood assets or the means of production available to individuals, households, or groups.

Climate changes cause local weather conditions including extreme heat and severe weather events – which affect public health in urban areas. Key health issues are impacts related to extreme temperatures, disasters, epidemics, health services, and psychological illnesses. It also considers how poverty acts as a compounding factor, which exacerbates the health impacts of climate change.

Equity

Vulnerability to climate change differs considerably across socioeconomic groups, thus raising important questions about equity (IPCC 2007c). The cardinal climate change inequity is consequently not the potentially unfair allocation of mitigation targets but the inevitably unfair distribution of climate impact burdens. Indeed it indicates that while "equity" is often put on the agenda by developing country experts, the scope of the agenda itself, namely, emission mitigation, has been firmly set by the industrialized world (Muller 2002).

Population

A statistical (time-series) analysis shows that over the past three decades, the proportion of the global population affected by weather-related disasters has doubled in linear trend rising from roughly 2 % in 1975 to 4 % in 2001 (Muller 2002).

Sociocultural Impacts

There is a strong association between rising income and car use in developing countries, meaning that economic growth in developing countries is very likely to result in increased car use and rising traffic congestion. In addition, in many developing countries, the stock of motor vehicles is old and consists largely of secondhand and less efficient vehicles imported from developed countries. At the same time, the conversion of vehicles to use different fuels has the potential to reduce GHG emissions in many cities in developing countries.

The tourism industry is highly dependent upon reliable transportation infrastructure, including airports, ports, and roadways. Climate change has the potential to not only shift regional temperature distributions but also increase the incidence of severe weather events, which would increase transportation delays and cancelations. Since recreational activities and tourism are often major sources of revenue for urban areas, when climate change impacts affect these activities, local urban economies will incur monetary and job losses.

The insurance industry is vulnerable to climate change, particularly extreme climate events that can affect a large area. Storms and flooding can cause significant amounts of damage and are often responsible for a large percentage of total losses.

Climate change could result in increasing demand for insurance while reducing insurability. Insurance industry catastrophe models forecast that annual insured claims and losses are likely to significantly increase over the next century as a result of the increasing intensity and frequency of extreme storm.

Community-based adaptation (CBA) to climate change has recently received more attention, although there is uncertainty about its potential. It is unclear, for example, how it fits in with community-based development and disaster planning among other more established development activities. It is also uncertain how different it is from other forms of adaptation and what particular potentials and limitations it will have when applied to urban areas (Satterthwaite et al 2007).

Social Impacts

The degree to which human settlements are vulnerable to climate change depends not only on the nature and magnitude of physical changes but also on the socioeconomic characteristics of each city.

Poverty

Climate change is considered a distributional phenomenon because it differentially impacts upon individuals and groups based on wealth and access to resources. In general, low-income households in both developed and developing countries are most vulnerable to climate change impacts primarily due to the scale and nature of the assets that they possess or can draw upon.

Gender

In most urban centers, there are significant differences between women and men in terms of their exposure to climate-related hazards and their capacity to avoid, cope with, or adapt to them.

Age

Young children are particularly vulnerable to climate change impacts, in part because of their physiological immaturity.

Ethnic and Other Minorities

Racial and ethnic minorities also exhibit increased vulnerabilities to climate change in both developed and developing countries. Discriminatory practices often segregate groups of minorities into the highest-risk neighborhoods, usually without access to insurance and loans as security against climate change impacts. The majority of flooding victims in Bihar (India) in 2007 were “untouchable” low-caste groups who resided in floodplains and areas prone to landslides.

The most vulnerable low-lying communities in New Orleans (USA) are comprised mostly of African-Americans. This group suffered the relatively most severe losses of life and assets during Hurricane Katrina.

Literacy

The Essential Principles of Climate Science is an interagency guide that provides a framework and essential principles for formal and informal education about climate change. It presents important information for individuals and communities to understand Earth’s climate, impacts of climate change, and approaches for adapting and mitigating change.

Production and Consumption Pattern

Total world energy consumption and CO_2 emissions continue to increase steadily. From 1990 to 2004, world energy consumption increased by about 30 % and CO_2 emissions by 26 %, while world GDP has increased by over 50 %. There have thus been modest improvements in overall energy efficiency (GDP per unit of energy consumed) and carbon intensity (CO_2 emissions per unit energy or GDP), but these improvements in efficiency have been overwhelmed by increasing production and consumption. As a result, the driving forces of human-induced climate change are steadily increasing and Sustainable Consumption and Production (2007) have been on the international agenda since Agenda 21 (1992) identified unsustainable patterns of production and consumption as the major cause of the continued deterioration of the global environment. The climate change impact of patterns and trends and policies and measures by which consumption patterns can be changed to promote sustainable development (United Nations Department 2007).

Governance

In least developed countries, the National Adaptation Programmes of Action to Climate Change (NAPAs) provide a starting point for identifying national priorities for adaptation to climate change. However, they rarely identify the need to work closely with local institutions in implementing priority actions on climate change. In addition, all countries signatory to the United Nations Framework Convention on Climate Change (UNFCCC) produce periodic “National Communications” on

Climate Change, which increasingly draw together both mitigation and adaptation issues, but again are not specific in terms of the role of local authorities. More recently, some countries (particularly middle-income countries) have moved toward the development of comprehensive national climate change strategies with high levels of visibility and political engagement.

Technology

Industrial sectors situated in urban areas or providing urban areas with the commodities. They need to function such as energy supply and demand. Mining and construction are generally thought to be less vulnerable to the impacts of climate change than agriculture, water, and other sectors and services dependent on climate. This is in part because their sensitivity to climatic variability and change is viewed as being comparatively lower and in part because industry is seen as having a high capacity to adapt in response to changes in climate.

Industry and Commerce

Industrial activities can bear potentially high direct and indirect costs from climate change and extreme climate events. Whether industries are located in the heart of urban areas or in adjacent suburban or rural areas, they provide services and resources that are vital to city function. Damage to industries due to climate events thus has direct and indirect impacts upon cities and their residents.

In 2011, there were nearly 1.2 billion passenger vehicles worldwide. By 2050, this figure is projected to reach 2.6 billion – the majority of which will be found in developing countries. The emissions associated with the increase in passenger vehicles can be reduced either through advances in fuel technology or by changes from one mode of transportation to another. The potential for such reductions is particularly strong in urban areas – with the advantage of relatively high densities of people, economic activities, and cultural attractions (Fig. 5).

Urbanization

When investigating urbanization, a need of clear definitions arises. What should be considered urban? There are a myriad of characteristics that can be used, most notably the presence of buildings and structures or people, but regardless of which are chosen, there are still lines to be drawn and assumptions to be made. In the United Nations publication *The State of World Population 2007* (UNFPA 2007), the definition of urban is based on definitions by national statistical agencies. Urbanization, on the other hand, is defined as an increase in the proportion of the population, which live in urban settlements.

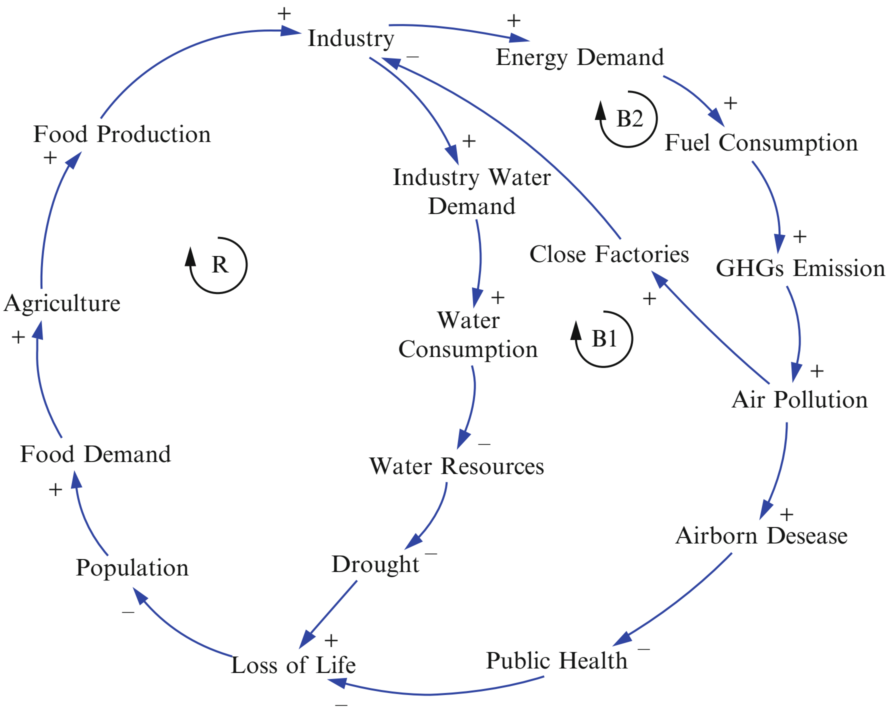


Fig. 5 Socioeconomic impacts

Developed countries and countries that benefit disproportionately from oil and coal industries must accept more responsibility for reducing emissions since they are responsible for the majority of emissions currently in the atmosphere (DePaul 2012).

Viewing the effects of urbanization as negligible on a global scale might be tempting. Urban areas cover only 0.046 % of the Earth's surface according to an estimation given in the Fourth Annual Report (AR4). This estimation, however, originates from global land cover data (Loveland et al. 2000), which for the urban areas used a data layer from the US Defense Mapping Agency's Digital Chart of the World (DCW; Danko 1992). The data layer, in turn, is drawn from map sources made between 1950 and 1979 as also pointed out by Potere et al. (2009). Needless to say, the extent of urban areas has increased dramatically over the last 60 years, rendering the global effects of urbanization progressively less negligible.

Extent of Urban Areas

With the problems previously discussed in finding a suitable definition of urban areas, it is natural that the actual extent of urban areas is still very much unclear. Data from the DCW (Danko 1992) has been widely used for a long time (Potere et al. 2009).

Location and Rate of Urbanization

Most cities are located between 30°N and 65°N (Jin et al. 2005), which, considering this area spans roughly from north Africa to the Arctic circle, is not surprising. Half of the world's population of about 6.4 billion people currently lives in urban areas, compared to less than 15 % in 1900. Many aspects of urban change in recent decades are unprecedented. The world's urban population increased more than tenfold during the twentieth century. The fastest growing cities are mainly concentrated in the world's largest economies (Satterthwaite et al. 2007). But unlike urbanization in the beginning of the twentieth century, mostly confined to countries with the highest levels of per capita income, the most rapid urban change is currently taking place in middle- and low-income countries, which host nearly three quarters of the world's urban population. In regard to climate change, urban areas house a large proportion of the population and the economic activities most at risk from extreme weather events and sea-level rise – and this proportion is increasing.

Why can urban development bring increased vulnerability to climate risks? The concentration in urban centers of people and their homes, as well as of infrastructures, industries, and wastes, has two implications for the urban impacts of climate change and other stresses. On the one hand, urban areas can be dangerous places to live and work; their populations can be very vulnerable to extreme weather events or other hazards with the potential to become disasters. For instance, urban concentration can generate risk when residential and industrial areas lack space for evacuation and emergency vehicle access, when high-income populations are lured by low-lying coastal zones, or when lower-income groups, lacking the means to access safer land, settle on sites at risk from floods or landslides. Urban settlements can increase the risk of concatenated hazards (Lavell cited in Satterthwaite et al. 2007). This means that a primary hazard (heavy storm) leads to secondary hazard (e.g., floods creating water supply contamination). It is possible that the impacts of climate hazards such as heat waves will overlap with pollution events and compound one another making urban disaster risk management even more complex. On the other hand, the same concentration of people, infrastructures, and economic activities in urban centers also means economies of scale or proximity for many of the measures that reduce risks from extreme weather events. Economies manifest themselves in the per capita cost of better watershed management, warning systems, and other measures to prevent and lessen the risks when a disaster threatens or occurs. Furthermore, when provided with policies focused on enhancing sustainability and moving from disaster response to disaster preparedness, urban settlements can increase their effectiveness at coping with climate hazards.

Urban development can relate to increased vulnerability to climate risks for several reasons. First, many cities have developed without consideration of the risks that climate change will carry with it. Most large cities have been built on sites that were originally chosen for trade or military advantage (e.g., Shanghai, New York, Buenos Aires). In the majority of cases, this has meant that they were located on the coasts or near the mouths of major rivers where trade by sea with other coastal cities or by rivers with the interior hinterlands could best be accomplished. These urban centers then became the hubs of trade for their countries and, as such, greatly increased their wealth.

As this wealth continued to build, further development was fueled, and these areas became engines of economic growth for their countries, attracting more capital from private sector investment and labor migration from rural areas and immigration from other countries. The movement to urban centers continues today, and these areas have become magnets of industry and labor without regard to the many environmental risks that are endemic to these areas and the mounting hazards that are predicted to be brought with climate change.

Urbanization is taking place at unprecedented rates, especially in small and medium cities. As migration has accelerated, the abilities of urban centers to accommodate their population have been put under increasing pressure, especially in middle- and low-income countries. Certain urban characteristics have relevance for understanding risks from climate and weather hazards (Satterthwaite et al. 2007).

Why are some sectors of the population more vulnerable? As was emphasized above, not all demographic segments of the urban population are equally affected by the hazards climate change is predicted to aggravate. Wealthy individuals and households have more resources to reduce risks, i.e., safer housing, more stable jobs, safer locations to live, and better means of protecting their wealth (e.g., insurance of assets that are at risk). Wealthier groups often have more influence on public expenditures. In many urban areas, middle- and upper-income groups have been the main beneficiaries of government investment in infrastructure and services. If government does not provide these, higher-income groups have the means to develop their own provisions for water, sanitation, and electricity or to move to private developments, which provide these. Wealthier groups, in short, have higher adaptive capacity.

The populations most at risk from climate change are those living in affected areas who: (a) are very young, already sick, or elderly; (b) lack the capacity to avoid the direct or indirect impacts by having such means as good quality houses and drainage systems that prevent flooding, by moving to places with less risk, or by changing jobs if climate change threatens their livelihoods; and (c) are least able to cope with the illness, injury, premature death, or loss of income, livelihood, or property caused by these hazards (Wilbanks et al. 2007; Satterthwaite et al. 2007). Impacts will also differ according to gender, as gender gaps exist in access to such determinants of adaptive capacity as access to resources, including credit, services, information, and technology, affects adaptive capacity. (Klinenberg (2002) and Cannon (2002) cited in flood plains, unstable slopes, over river basins, and other riskiest areas (Hardoy et al. 2004). Many poor populations face additional risks: they live in informal settlements, work within the informal economy, and are constantly faced with the possibility that governments may forcibly move them off land sites deemed to be vulnerable to weather risks but away from their means of livelihood (Satterthwaite et al. 2007). They may also be moved simply because other actors want the land they occupy for more “profitable” uses.

Furthermore, poorer groups are affected most by the combination of greater exposure to other urban hazards (sanitary conditions, lack of hazard-removing infrastructure). They have less state provision to help them cope and less legal and less insurance protection. Low-income groups also have far fewer possibilities to move to less dangerous sites. This should not lead us to conclude that the poor are passive recipients of all of the risks of climate change and other hazards. They have developed mechanisms to adapt. It only means that structural issues as those referred here pose limits to their coping mechanisms.

What societal and environmental factors underlie the trajectories of emissions by cities? Just as urban centers register different levels and paths of development, cities do not contribute at the same level to global warming. Some scholars point to the fact that urban centers in low-income countries have lower levels of emissions per capita than cities in high-income countries (Wilbanks et al. 2007; Satterthwaite 2008). In fact carbon emissions per capita in cities from high-income countries such as Texas and the District of Columbia are 19- to 20-fold as high compared with those in Sao Paolo, Delhi, and Kolkata. Yet, other wealthy cities such as Stockholm and Barcelona have lower levels of emissions per capita than the four South African cities. Why is this so? Definitive answers to this question cannot be provided, because existing data on emission levels cover very few cities and have not been gathered applying similar or comparable criteria. As a result, it is difficult to apply such statistical tools as regressions or correlations to explore the role of affluence, population dynamics, climate, and other drivers in explaining the levels of carbon emissions by urban centers.

Cities' Responses to Climate Change

It has been recently recognized that urban areas play a key role in addressing the challenges created by climate change in terms of mitigation and adaptation alike (Sanchez-Roman et al. 2009). Different initiatives such as the Cities for Climate Protection, the C40 Cities Climate Leadership Group, and the Majors Alliance for Climate Change Protection in the USA are examples of current responses. A high proportion of these initiatives have been created in large cities of high-income countries and to a lesser extent of middle- and low-income countries.

Urban Infrastructure

Urban infrastructure – in particular, energy (electricity and gas) networks and water and sanitation systems – is critical in shaping the current and future trajectories of GHG emissions. The type of energy supply; the carbon intensity of providing water, sanitation, and waste services; and the release of methane from landfill sites are important, though often hidden, components of GHG emissions at the local level. A dynamic, complex, and strong link exists between economic development, urbanization, and GHG emissions.

Strong evidence exists showing that demographic change is closely associated with greenhouse gas emissions, and future trends in population dynamics will play a key role in attempts to mitigate and adapt to the effects of changes in the climate system. It is clear, in addition to population size, that analyzing the compositional change of populations, specifically the age composition, the distribution of people in urban and rural areas, and household size and composition, is very important for understanding future needs and potential for mitigating carbon emissions and climate change. The analysis presented in this chapter shows that by only including population size as the demographic variable in climate models, the contribution of "population" to climate change has been underestimated. The indications are that the combined influence of climate change and urban growth on the urban flooding situation is significant indeed.

Land-Use Change

The assessment of the contribution of land cover change in the AR4 focuses mainly on deforestation since 1750 and suggests a net cooling effect since croplands, for example, usually have a higher albedo than forest. That is, they reflect a higher portion of the incoming solar radiation. A specific land cover change that could reduce this cooling effect is urbanization. Conversion of high-albedo surfaces such as some croplands into urban surfaces like asphalt or dark walls can lower the albedo considerably. While the AR4 recognizes that urbanization may alter local and regional climates in several ways, potential effects on the global scale are largely overlooked.

The focus on albedo and urban environments requires thorough explanations of the Earth's energy balance, of the definition of albedo itself, and of specific urban climate effects.

Land Use

Feddema et al. (2005) and Roger and Pielke (2005) among others agree that land cover changes need to be included when analyzing global climate change. To fully appreciate the effects of land cover change, urbanization cannot be ignored.

Albedo

The aim of this part is to investigate the climatic effects of urbanization with special focus on albedo and to review the nature and magnitude of urbanization.

A specific climatic effect of urbanization, which has not received as much attention as it might deserve, is the change in the reflective properties of the surface. This section aims to investigate the climatic effects of urbanization, especially albedo (the ratio of incoming to outgoing solar radiation for a given surface).

Urbanization has many effects on surface albedo. It reduces it through the introduction of dark surfaces, through changing the surface geometry to better capture solar radiation, and through reducing snow cover in winter. It can also increase it by increasing the cloud cover and by emitting air pollutants and aerosols. Some effects, such as a modified surface moisture regime or climate changes downwind of cities, can act to both reduce and increase it, with the net effect very dependent on local factors.

The radiative forcing of this albedo reduction is very small. This is mainly because the fraction of Earth's land surface covered by urban areas is only 0.44 % according to the best estimate. While the climatic effects of albedo change due to urbanization are small on a global scale, they are quite distinct on regional to local scales. The small extent of urban areas today is still more than twice as large as the estimate cited in the last assessment report by the IPCC (AR4). With the projected increase in urban populations, the small global effects will become progressively more important and will need to be taken into account in future studies of climate and land-use change.

Urban Climate

Urban areas are among the most altered environments on Earth. From cities to suburbs, the materials composing the surface are determined by their use to humans. The surface geometry is related to human concepts such as construction cost, design, and tradition. What species of plants and animals live here are accepted by human society or deemed too expensive to remove. Changes affect quantifiable climatic variables including temperature, wind patterns, precipitation, evapotranspiration, and even incoming solar radiation (Oke 1987; Collier 2006).

Many studies have shown the potential of urban areas to increase rainfall in and downwind of them (Shepherd et al. 2002; Jauregui and Romales 1996), but there is still a need for more research on the matter, evident by the criticism delivered by Diem et al. (2004) and subsequent replies.

Shepherd et al. (2002) outlined four primary ways in which urban areas change natural precipitation patterns, namely, by:

1. Creating, enhancing, or modifying mesoscale circulations and thus destabilizing the atmosphere
2. Promoting convergence of air near the surface through high surface roughness
3. Increasing the amount of condensation nuclei, for example, from pollution
4. Adding moisture to the air from industrial sources

In their study, rainfall increased on average 5.8 % over the cities examined and 28.4 % over downwind areas, compared to upwind control areas. In another study (Burian and Shepherd 2005), average warm-season rainfall in Houston, Texas, USA, was increased by 25 % between a pre-urban and post-urban period (1940–1958 and 1984–1999). Such an increase in rainfall may correspond to an increased cloud cover, in which case the reflection of incoming short-wave radiation is increased while more long-wave radiation is absorbed and reradiated to the surface. As mentioned, aerosols and other atmospheric constituents act to scatter and absorb radiation, so the addition of pollution to the atmosphere reduces the short-wave radiation reaching the surface (Solomon et al. 2007).

Cities as Drivers of Global Warming

Cities have often been blamed for causing air and water pollution and currently for causing global warming. Yet, do we have any consistent measure of cities' contribution to global GHG emissions? The next sections will address the questions of how much we actually know about how cities generate GHG and impact the atmosphere. We will also look at whether, within our current knowledge, we understand the societal and environmental drivers of the different trajectories of emissions by cities.

How Big is the Contribution of Urban Centers to Global Warming?

To understand how urban centers generate GHG, it is necessary to find a representative measure of carbon emissions (Molina and Molina 2002). Different issues need to be considered here. First, there is a paucity of data limiting the scope of any study exploring how big urban contribution to global emissions is. The second relates to the activities generating those emissions. Most of the total pollution comes from the combustion of fossil fuels (coal, oils, and natural gas) for heating and electricity generation for consumption by commercial and residential buildings, for running motor vehicles, and in industrial processes. Other sources are households consuming fuels in heaters and cookers, or indirectly in air conditioning. It is also usual to find carbon emissions resulting from land-use changes and aggravated by poor land management and many unpaved roads. Landfill sites taking urban wastes are another key source of methane. The manufacturing process used in the production of cement needed for the development of our urban areas can also account for as much as 5 % of global emissions of GHG. Finally, many activities undertaken outside the boundaries of urban centers such as agriculture and cattle, aimed at satisfying urban requirements of food, raw materials, forest products, and construction materials as well as electricity generation in rural areas but largely for urban use, also contribute to carbon emissions.

Second, GHG emissions are formed through different processes and have a residence time before being absorbed by the atmosphere or the oceans ranging from 3–4 years (CO_2) to 8–10 years (Methane) and even 50–100 years (Molina et al. 2002). Third, the impacts of urban emissions range from destruction of ecosystems to photochemical smog and from acidifying emissions to global warming (Molina and Molina 2002; Hardoy et al. 2004). All these impacts impair the health of populations and ecosystems in direct and indirect ways (Molina and Molina 2002).

Last but not least, many scholars, practitioners, and policy makers claim that cities are sources of most of the world's greenhouse gas emissions. Large cities take up only 2 % of the Earth's land mass, but they are responsible for about 75 % of the heat-trapping greenhouse gases that are released into our atmosphere.

Effects on Albedo from Urbanization

In a global perspective, urban albedo change needs to be considered in relation to the albedo of the replaced surface. As a rough example, paving a desert road with an initial albedo of, say, 0.40 with a resulting albedo of 0.10 is a considerable reduction. Paving a road through a coniferous forest after clearing a path might, on the other hand, double the albedo from an already low 0.05. In the same way, albedo changes due to urbanization need to consider previous land cover. Since potential natural vegetation as well as agricultural practices (such as choice of crops) vary with climate, the latitude of a city influences its impact on albedo.

Dark Surfaces

The introduction of dark impervious surfaces is a common and important feature of urbanization.

Many construction materials have lower albedo than nonurban surfaces. Offerle et al. (2003) reported, for example, that roofs and asphalt paving covered 49 % at a site in Chicago and 15 % in a Los Angeles residential area, which has large effects on urban temperatures. Wu and Murray (2003) found impervious surfaces to cover 75 % of a central business district site in Columbus, Ohio, of which a large portion consists of low-albedo surfaces such as asphalt.

Surface Geometry

As mentioned before, the geometry of the urban environment affects albedo in the same way vegetation canopies do, by enabling multiple reflections of the incoming short-wave radiation.

In modeling contexts, the concept of urban canyons is frequently used to describe a generalized situation (Oke 1987).

Increased Cloud Cover

From studying satellite Advanced Very High-Resolution Radiometer (AVHRR) images, Inoue and Kimura (2004) saw a clear increase in low-level cloud cover over urban areas of Tokyo, Japan. The processes responsible were hypothesized to be the higher sensible heat flux leading to an increased height of the mixing layer, so that clouds can form at the top of the enlarged thermals (warm rising air volumes), and also convergence and uplift of air due to local circulation induced by the urban to rural temperature contrast.

Effects from Urbanization Outside of Urban Areas

All modifications of air properties by urban areas, such as the cloud formation and precipitation tendency already discussed or air pollutants, can be transported downwind of its origin in the urban plume (Oke 1987). Thus, the effects of these urban modifications on albedo canal so occur outside of urban areas. Pollutants, for example, which contribute to atmospheric scattering and absorption thereby reducing the incoming short-wave radiation, can act in the same way over downwind rural areas.

Radiative Forcing of Urban Albedo Change

Radiative forcing, as outlined by the National Research Council (NRC 2005), is basically any climate forcing that affects the radiation balance. Pielke et al. (2002)

hypothesized that the radiative forcing of global surface albedo changes due to land cover changes may be comparable to the forcing of solar variability, anthropogenic aerosols, or to some of the greenhouse gases. They also suggested that more regional metrics need to be considered because of the potentially large offsetting regional changes, which would be masked by global averages.

In the latest IPCC report AR4 (Solomon et al. 2007), the radiative forcing of surface albedo change in general was suggested to be between 0 and –0.4 W/m^2, and the level scientific understanding was raised from low to medium-low.

Impacts on Anthropogenic Energy Consumption

In contributing to the UHI effect, urban albedo changes modify human energy needs for cooling or heating buildings. That increasing the albedo of buildings can be an effective measure to reduce energy demand (Akbari and Konopacki 2005). They estimate an annual electricity savings potential of 1294 GWh in Houston, Texas, from the combined use of reflective roofs, tree shading, and urban reforestation.

Climate Change in a Holistic View

See Fig. 6.

Case Study (Tehran Megacity)

If natural disasters, land degradation, and conflict result in sudden mass movements of people, megacities may experience the “urbanization of poverty,” which would send shocks through societies and the global economy as prospects for equitable economic growth deteriorate. While it would be wrong to generalize that these claims apply to all of the world’s 26 megacities, the policy issues at hand could certainly become salient in megacities like São Paolo, New York City, and London, where mass urbanization and climate changes are already major concerns for local governments.

Over 900 million people – more than 70 % of urban populations in developing countries – currently live in slum-like conditions, 151 with this number expected to increase to two billion over the next 30 years (Little and Cocklin 2009). Slum-like conditions are characterized by “low incomes, poor housing and provision of basic services, and no effective regulation of pollution or ecosystem degradation” (Campbell-Lendrum and Corvalan 2007) (Figs. 7 and 8).

Climate Change Scenarios

SRES scenarios (economic-social-population) have been developed by IPCC by which the world situation is evaluated in terms of environmental and economy in

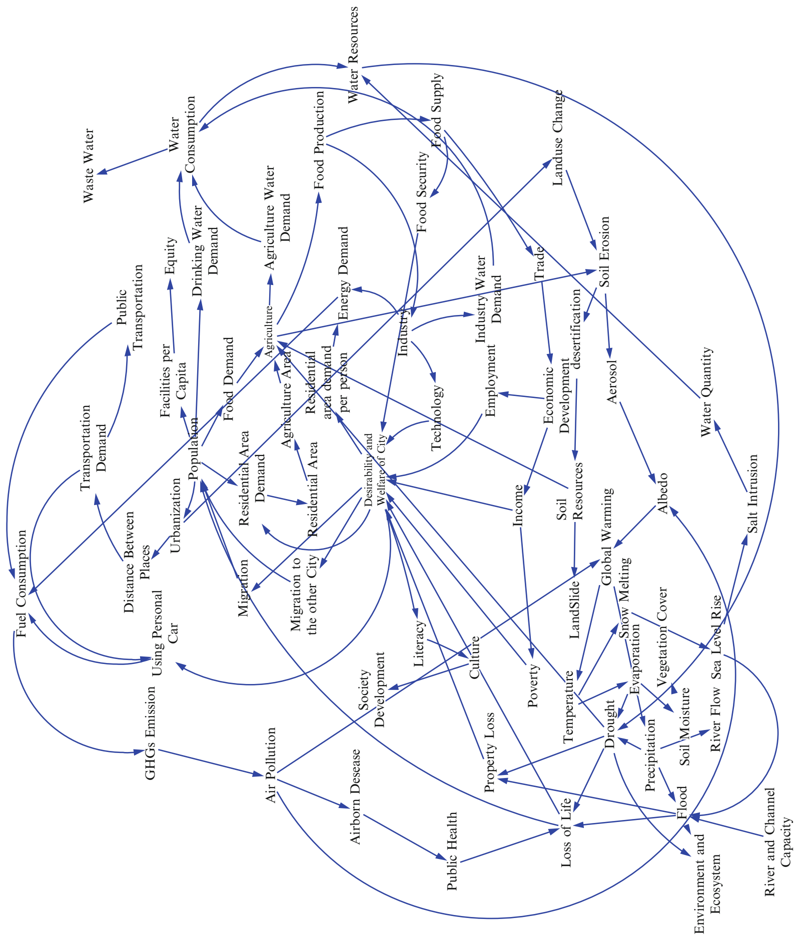
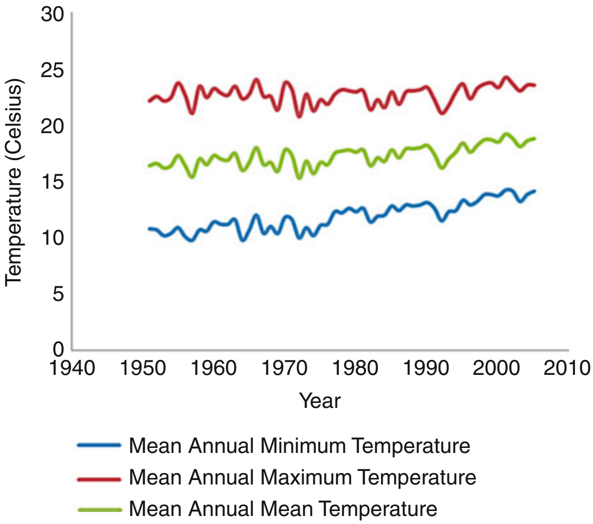


Fig. 6 Climate change drivers and interaction between them

Fig. 7 Temperature increase



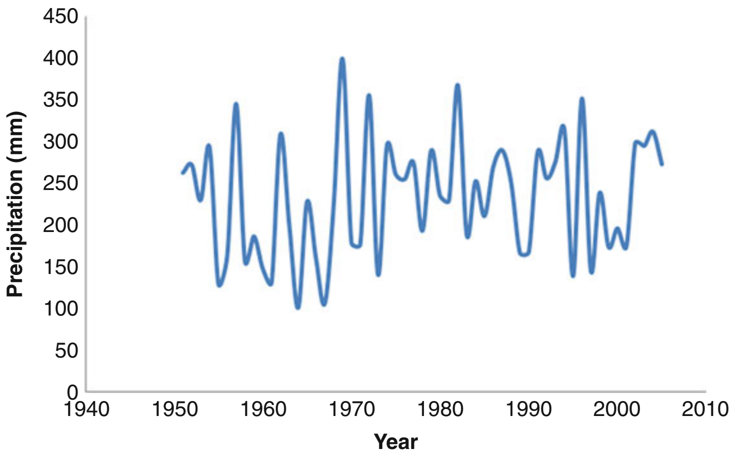


Fig. 8 Precipitation

two scales of global and local-regional. These scenarios are classified into four categories: A1, A2, B1, and B2.

In this research, A2 and B2 have been used for the basic period from 1951 to 2005 and the future period from 2016 to 2070. In addition, Hadcm3 model was applied based on the aforementioned scenarios and the study periods. In this regard, in order to downscale the climate change data, IDW method has been used.

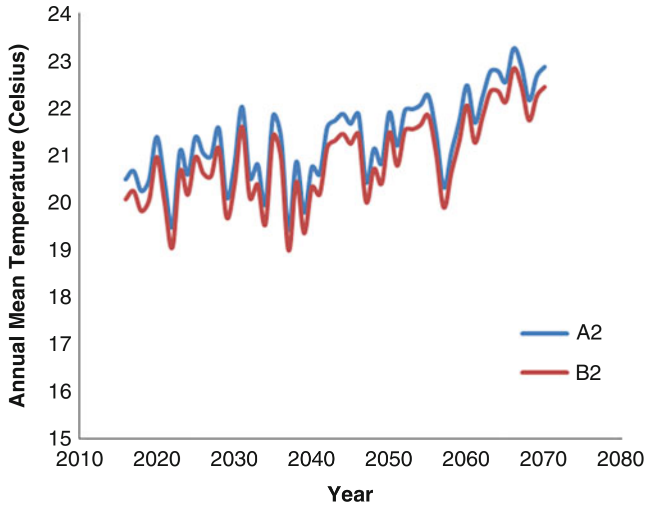


Fig. 9 Mean temperature

The results show an increase in mean monthly temperature in 55 prospective years (2016–2070). The highest mean monthly temperatures were observed in June, July, and August as many as 5 °C, 5.1 °C, and 4.9 °C in A2 and 4.9 °C, 4.9 °C, and 5.4 °C in B2 correspondingly.

In addition, there is an increase in the mean temperature in the prospective period (Fig. 9).

The highest monthly temperatures in the given future period compared to basic period in A2 scenario have been observed in May (5.1 °C), June (5.7 °C), and July (4.98 °C) and in B2 scenario in May (5 °C), June (5.34 °C), and August (5.57 °C) (Fig. 10).

Based on both A2 and B2 scenarios, the minimum temperature in prospective 55 years compared to the basic period has positively increased so that in some months, the minimum temperature has been increased as many as two times. In general, mean temperature, maximum temperature, and minimum temperature of the region will experience an increase (Fig. 11).

Based on the results, it is clear that according to both scenarios the most decrease in precipitation will be observed in May, June, and July. These decreases in A2 scenario are 22.26 %, 27.34 %, and 18.8 % correspondingly and 24.44 %, 22.8 %, and 21.4 % in B2 scenario compared to the observed period. On the other hand, according to A2 scenario, there is an increase in the amount of precipitation in wet seasons and months such as October and November by 1.7 % and 3.6 % correspondingly. Hundred percent of the increase in October is happened through the last 25-year period (2046–2070), and 88 % of this increase in November is occurred through 2046–2070. In addition, based on B2 scenario, 3.8 % and 13.16 % increase

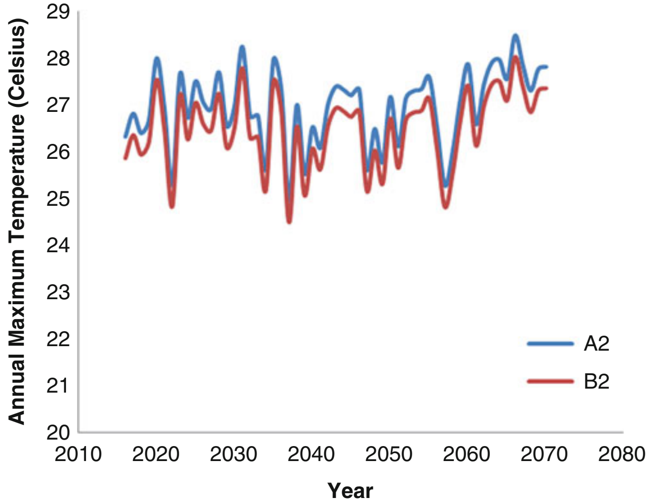


Fig. 10 Maximum temperature

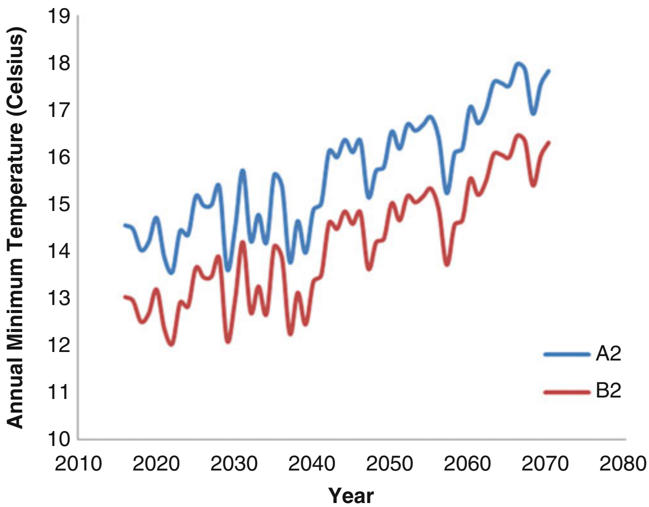


Fig. 11 Minimum temperature

in January and November have been observed correspondingly. Seventy percent of the increase in January is related to the last 25 years of the study period, and the 70 % of the increase in November is occurred in the first 30 years of the period (2016–2045) (Fig. 12).

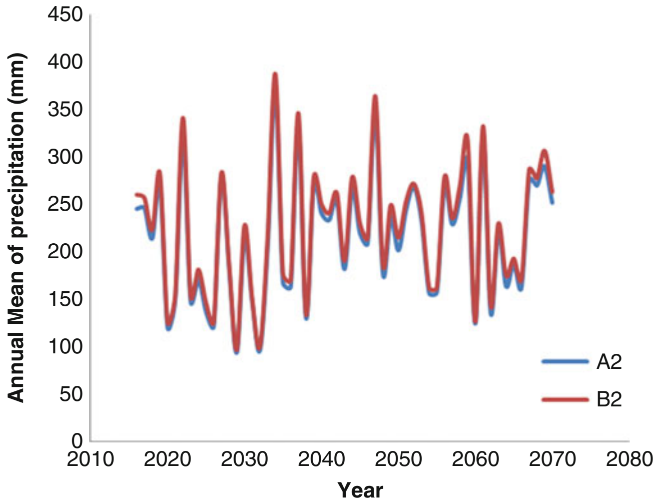


Fig. 12 Precipitation

Conclusions

There are many policy options to choose from. Climate change can be addressed through emission pricing (introducing a carbon tax), emission caps (establishing a cap-and-trade system), voluntary emission reduction targets and incentives for industry, and research funding for and development of new emission-reducing technologies.

The effects of urbanization on Earth's albedo are as diverse and heterogeneous as the urban fabric itself. While some aspects of urbanization tend to reduce the albedo compared to nonurban areas (e.g., dark surfaces, surface geometry, reduced snow cover in winter), some may increase it (e.g., increased cloud cover and air pollution), and some are still too poorly understood to make an assumption (e.g., modified surface moisture regime and downwind effects). It was found from satellite comparison between urban and cropland albedo that urban surfaces have 2–5 % lower.

The extent of urban areas is unclear and depends largely on the definition of urban areas, but the best estimate tends toward 0.44 % of the land surface in 2001, well over twice that cited by the IPCC in the AR4, which bases its estimation on up to 60-year-old data.

Increasing the albedo of all urban areas, globally, by 0.01 is calculated to exert a negative radiative forcing of less than 0.01 W/m^2, or more than 20 times smaller than the negative radiative forcing estimated by the IPCC for all land cover change since preindustrial times. Further expansion of urban areas into high-albedo areas such as croplands or deserts would result in increased warming. However small, this warming reduces the net cooling effect of land cover change.

By comparing the contemporary reality that more people live in cities than rural areas to the fact that only 13 % of the world's population lived in cities during the early twentieth century, it is evident that mass urbanization will impose societal, economic, and cultural pressures on urban centers, since there is currently less space and fewer resources to be shared or distributed (Bhagat and Mohanty 2009). Pressures include new burdens on transit infrastructure, increased competition for jobs, and reduced provision of social services. Instances of xenophobia may increase because some people might make a connection between migration and deteriorating conditions.

According to a publication by the United Nations Population Fund (UNFPA 2007), the size of the world's urban population will have grown to 4.9 billion people by 2030, with most of the growth occurring in the developing world.

Megacities are defined as metropolitan areas with a total population in excess of 10 million people (Rana 2011).

The World Health Organization (2008) reported that a warmer and more volatile climate is expected to increase the already high instances of annual deaths related to natural disasters (60,000), urban air pollution (800,000), diarrhea (1.8 million), and malnutrition (3.5 million).

As Adamo (2010) points out, "a large proportion of urban expansion is taking place in areas exposed to environmental hazards, [for example] low lying plains, coastal zones, stepped slopes and dry lands."

As evidence on the implications of a changing climate builds, migration is becoming a salient consequence of unabated greenhouse gas (GHG) emissions and poor climate risk adaptation (DePaul 2012).

Millions of people move each year, with over five million crossing international borders into developed countries and even greater numbers moving into or within developing countries.

Various strategies of land-use planning have been used in order to limit urban expansion, reduce the need to travel, and increase the energy efficiency of the urban built form.

In developing countries, there are few initiatives to explicitly mitigate climate change through urban design and development. In developed countries, private developers and community groups have led new urban development, brownfield regeneration, and neighborhood renewal projects, which seek to address climate change. Policy approaches for reducing GHG emissions from the built environment have primarily focused on issues of energy efficiency.

Climate change is having real impacts on migration patterns and, in turn, the capabilities of megacities to accommodate influxes of people.

First, sudden-onset climate-related disasters such as floods and hurricanes are push factors that are already resulting in forced migration from disaster areas.

Second, slow-onset climate impacts such as soil erosion and desertification are push factors, which magnify current "interacting physical and social variables, including agricultural and economic decline that ultimately force people from their homelands" (Homer-Dixon 1991).

A third climate-related push factor category marries the first two categories above: slow-onset climate impacts and sudden forced migration. A changing climate's impact on agricultural production and natural resources will lead to what Thomas Homer-Dixon (1991) calls "acute national and international conflict."

Migration patterns will be especially affected by sea-level rise and riverbank erosion, which are already contributing to "impoverishment and marginalization of rural families due to the loss of productive agricultural lands" (Poncelet et al. 2010).

An estimated 20 million Bangladeshis are living illegally in India, a situation that has become "a major source of tension between the two countries" and has generated "a host of destabilizing political, social, economic, ethnic, and communal tensions in many states and union territories of India" (Alam 2004).

Rigorous climate change mitigation and adaptation policies are needed to avoid such scenarios all around the world. Likewise, a normative shift is needed, particularly in climate-sensitive regions and security discourse, to redefine what is threatening. The cases of Bangladesh and India indicate that the real threat is climate change, not migrants. Without addressing the causes and effects of climate change, what many people perceive as threats from migration will never be resolved.

In 1990, the Intergovernmental Panel on Climate Change (IPCC) noted that the greatest single impact of climate change could be on human migration especially to urban centers – with millions of people displaced by shoreline erosion, coastal flooding, and agricultural disruption (IOM 2008). Since then various analysts have tried to put numbers on future flows of what came to be called "climate refugees." Yet it has been difficult to establish a predictive line of causation between climate change and migration (IOM 2008). This is so because finding the primary causes of migration is highly problematic, not least because individual migrants may have multiple motivations, and be displaced by multiple factors (Black 2001). For instance, studies of displacement within Bangladesh, and to neighboring India, have drawn obvious links to increased flood hazard as a result of climate change. However, such migration also needs to be placed in the context of changing economic opportunities in the two countries and in the emerging megacity of Dhaka, the encouragement of migration by some politicians in India, rising aspirations of the rural poor in Bangladesh, and rules on land inheritance and on ongoing process of land alienation in Bangladesh (Abrar and Azad 2004 cited in Wilbanks et al. 2007).

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Would Climate Change Affect the Imports of Cereals? The Case of Egypt

Suzanna El Massah and Gehad Omran

Contents

Abstract

Climate change is recognized to be the greatest environmental problem facing the whole world due to its adverse impacts especially on the agricultural production, which is expected to vary across the countries. Within the context of Egypt's dependence on cereal imports to fill its production gap, this chapter shows that the climate change is expected to indirectly affect these cereal

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imports, namely, wheat and maize, through affecting the cereal production in the major exporting countries.

Specifically, the chapter concludes a positive relationship between the Egyptian imports of wheat from the USA and the climate change presented in its impact on wheat production in the USA and on the contrary a neutral and negative relationships for both the Egyptian imports of wheat from Russia and imports of maize from the USA and Argentina.

Accordingly, the chapter recommends diversifying the import markets of cereals to Egypt to prevent the domination of few countries on the imports of such strategic commodities as wheat and maize, in addition to the urgency of enhancing the domestic production through applying the suitable adaptation and mitigation methods to face the expected negative impacts of climate change on cereal production in Egypt.

Keywords

Climate change • Greenhouse gases (GHGs) • Agriculture • Cereal(s) • Wheat • Maize • Imports • Egypt

Introduction

Climate change is one of the overwhelming environmental threats that are defined as a long-term alteration in the global weather patterns, including the temperature, precipitation, soil moisture, sea level, and storm activity. Such climate change is a potential consequence for releasing the greenhouse gases (GHGs) that accumulated in the atmosphere, resulting the global warming.

Climate change is expected to have many adverse impacts on various sectors, yet agriculture is considered to be the most tangible affected sector, as any alteration in the prevailing temperature or precipitation patterns will disturb the agricultural sector as a whole, including the productivity, crop yields, and soil fertility.

However, impacts of climate change on the agricultural production are expected to vary across the world, where some countries are expected to benefit, while others are expected to suffer as the African countries, which are threaten not only by losing their agricultural production, but also by losing their imports from the countries which will be negatively affected from the climate change.

The agricultural sector in Egypt is considered to be one of the vital contributors to the Egyptian economy; it shares by about 20 % in the GDP and employs around 30 % from the total labor force.

The importance of this research is derived from the dependence of Egypt – alike many other developing countries – on importing strategic commodities (cereal and wheat in specific) to fill its production gap; self-sufficiency of Egypt in wheat was only 40.5 % in 2010. However, these imports are threatened by the expected impact of the climate change on the production of cereals in the major exporting countries. Such threat would affect negatively the Egyptian social and economic life of Egypt.

Accordingly, the main goal of this research is to identify how would the cereal imports to Egypt be affected due to expected climate change. Our research is based on the expected production variations of the major exporting countries. The results of this study will help form the necessary actions and adapt the appropriate policies to deal with the expected availability of these strategic commodities in the future.

Consequently, this study tries to answer the following question:

- What is the economic impact of the global climate change (GCC) on Egyptian imports of cereals? Other sub-questions are answered as well:
- How to identify GCC, its causes, and its impact on the agricultural sector?
- What are the major international agreements for the GCC?
- What is the contribution of Egypt in GCC problem, and what is the impact of the GCC on various sectors in Egypt?
- How to measure the impact of the GCC on cereal imports (wheat and maize) to Egypt based on the expected production variations in major exporting countries?

Hypothesis and Methodology

The research is based on assuming an indirect relationship between cereal imports to Egypt and global climate change, through its impact on the production of cereals and hence the exports of the major exporting cereal countries to Egypt. Hence, the focus is solely on the impact of global climate change – through temperature variations – on the Egyptian imports of cereals, while keeping all other variables constant, including the overall domestic and international prices, the competitiveness of the market and/or the product, market competition, political relationships, and any other variable that could affect the Egyptian cereal imports except the global climate change.

The authors use analytical and qualitative methods to achieve the goal of this research. Moreover, the multiple linear regression model is applied to examine the indirect impact of climate change, presented in the production variations in the major exporting countries, on the cereal imports to Egypt using the available annual time series from 1991 till 2011.

The study focuses on the imports of wheat and maize due to their relative production and trade importance for Egypt. Additionally, the USA, Russia, and Argentina are selected as being the major exporters of wheat and maize to Egypt.

Introducing the Global Climate Change

Climate change is one of the greatest challenges facing the whole world, threatening the future development, peace, and prosperity. Climate change is predicted to disturb the global weather conditions including temperature, precipitation, sea level, and frequency of extreme events.

The most common definition for the climate change is that mentioned in the United Nations Framework Convention on Climate Change (UNFCCC), which defines it as the change of climate that is attributed directly or indirectly to the human activity altering the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods (UNFCCC 2007).

It is worth noting the difference between climate change and global warming, in which the first refers to a significant change from one climatic condition to another including changes in temperature, precipitation, wind, and humidity, unlike global warming that shows the average increase in the temperature of the Earth's surface (ICTSD-IPC 2009).

Climate has been obviously changed during the twentieth century, in which the global mean surface temperatures have increased by 0.6 °C and nighttime minimum temperatures have increased at twice the rate of daytime maximum temperatures. Also, sea levels have risen by 10–20 cm and at an average annual rate of 1–2 mm.

Furthermore, although heavy precipitation events have increased over middle and high northern latitudes, the tropical regions especially in Asia and Africa have experienced drier conditions specifically during winter; continental precipitation as well have increased by 5–10 % in the Northern Hemisphere and decreased in other regions as in North Africa. Furthermore, the frequency and intensity of droughts have increased (IPCC 2001). Although the climate is changing naturally throughout its history, the rapid warming seen today and the increased rate of climate change are attributed mainly to human activities (IPCC 2001). The causes of the climate change are classified into natural and anthropogenic ones (Fig. 1).

Although there are natural factors changing the climate, the anthropogenic causes due to human activities are responsible for aggravating such normal changing, through two main factors:

First: Greenhouse gases (GHG), as shown in Table 1, in the form of carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons.

World GHG emissions have increased by about 20 % in only 15 years from 1990 to 2005, as shown in Fig. 2. Despite the existence of several GHGs, the carbon dioxide (CO_2) constitutes the largest share in the total GHG emissions (WRI 2012), indicating the growing use of fossil fuel.

Second: Changing land-use patterns. Various human activities such as the modification in agriculture and irrigation patterns, deforestation, and reforestation have altered the physical and biological properties of the land surface, by affecting the roughness of the absorbed solar radiation, increasing evaporation, and accelerating transpiration rate. Furthermore, it reduces the land's capacity to absorb carbon dioxide and increases the carbon emission from the land by enhancing the biomass decay, causing greater concentrations of GHG and disturbing the global climate (IPCC 2001).

Fig. 1 Cause of GCC

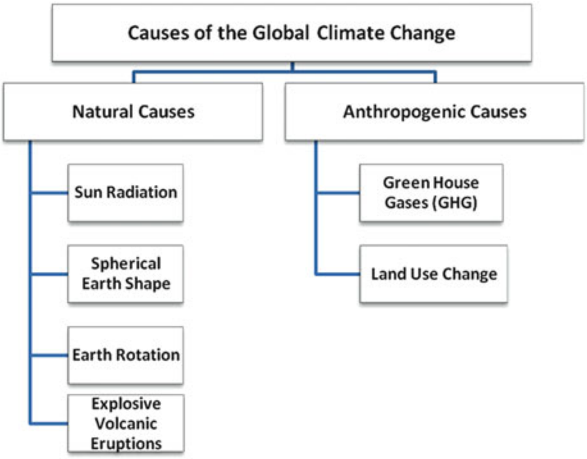


Table 1 Sources of GHGs

GHGs	Principal sources
Carbon dioxide (CO_2)	Burning of fossil fuels
	Electricity, transportation, and the increasingly energy-intensive standard of living
	Oxidation of biomass and the decomposition of the soil resulting from deforestation (burning or cutting of trees for agriculture and cattle ranching) release carbon stored in vegetation and in soil's organic matter into the atmosphere and reduce the number of trees available to absorb carbon dioxide
Methane (CH_4)	Emissions released from agricultural production especially rice paddies and other sources including emissions from landfills, coal mining, natural gas drilling, and leaking gas pipelines
Chlorofluorocarbons (CFCs)	Refrigerants propellants
	Aerosols
	Foaming agents and solvents
Nitrous oxide (N_2O)	It is elevated as result of
	Burning the fossil fuels
	Car emissions
	Expanding the use of nitrogen-based fertilizers

Climate Change and the Agriculture Sector

Agriculture is extremely vulnerable to climate change in that any alteration in the prevailing climate conditions as in temperature or precipitation patterns is expected to affect the agricultural sector as a whole, including the productivity,

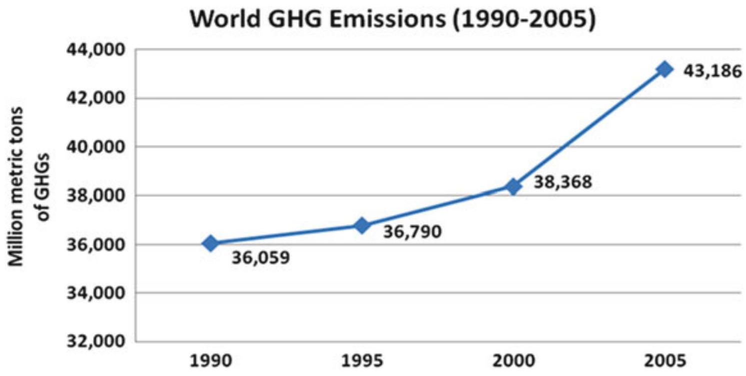


Fig. 2 World GHG emissions (1990–2005)

crop yields, and soil fertility. Yet such changes vary considerably across regions; climate change is expected to change the geographic distribution of the agricultural production, in the favor of higher latitudes and against lower ones which will be negatively affected (IPCC 1996). Latitude specifies the north-south position of a country on the Earth's surface. Higher-latitude countries are those countries lying far from the equator or near the north or south poles and characterized by being colder than the low- and middle-latitude countries due to their location far from the sun rays. Classifications for countries by latitude and world climate map are mentioned in the Annex. This shift in production potential will have to coincide with higher trade flows for agricultural products such as cereals from mid to high latitude to low latitudes, for example, cereal imports to the developing countries are estimated to rise by 10–40 % by 2080 (Huang et al. 2010).

Climate change projections vary; hence different expectations about its effect on agriculture are calculated. Changes in temperature, precipitation, and CO_2 concentrations could result whether in reductions or increases in growth, productivity, and water needs by crops. The direction of such effects depends on several factors such as the crops themselves: some are more sensitive to changes in temperature or CO_2 levels than others; for example, wheat is more sensitive and responsive to the CO_2 increase than maize. The location is another factor; grain crops in northern locations are more likely to benefit from additional heat and increase their yields, while in southern locations, yields are more likely be reduced. Accordingly, the coming analysis will be divided, as shown in Fig. 3, into the effect through temperature and the effect through CO_2.

The Impact of Higher Temperature on Agriculture

The increase in temperature is expected to affect the agricultural process in several ways.

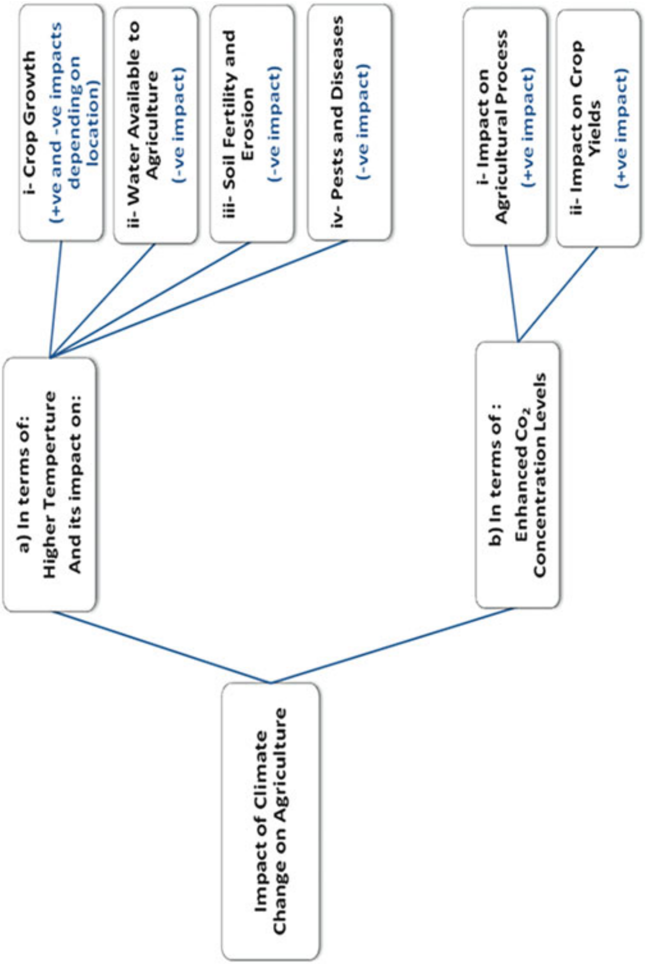


Fig. 3 Impact of climate change on agriculture

The Impact of Higher Temperature on Crop Growth

One of the most important positive effects of the increase in temperature, especially in middle and higher latitudes (e.g., USA, Europe, Australia), is improving the conditions for crop growth through extending the length of the potential growing season, reducing the growing period required by crops for maturation, and thus allowing earlier maturation and harvesting, as well as increasing the possibility of completing two or more cropping cycles during the same season and the likelihood of expanding the crop-producing areas, despite the probability of decreasing the yields in higher latitudes due to the less fertile soils that lie there (Rosenzweig and Daniel 1995):

> So, in middle and high latitudes, increasing temperatures may benefit crop development, which is currently limited by cold temperatures and short growing seasons. However, when temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield, as high temperatures accelerate the physiological development, and hence leading to hastened maturation and reduces crop yields by up to half if it coincides with a critical phase in the crop cycle like flowering. (Rosenzweig and Daniel 1995)

On the other hand, increased temperature in warmer/lower-latitude regions is expected to accelerate the respiration rate, at which plants release CO_2 causing less than optimal conditions for net growth (Rosenzweig and Daniel 1995), and increases the evaporation rates therefore reduces the moisture availability which then affects the yields' negatively (Parry 1990). Moreover, higher temperatures during the growing season speeds the development of annual crops, especially in the grain-filling stage, thus allowing less grain to be produced (Downing 1996):

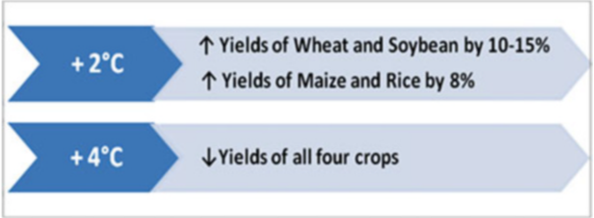
> So crop growth in most of the developed countries (middle and higher latitudes) will benefit from the increase in temperature, comparing to the developing ones (lower latitudes) which will be negatively affected.

Regarding the impact of temperature increase on cereals, which is the concern of this paper, the average crop yield – weighted by national production – shows a positive response to +2 °C warming and negative response to +4 °C, withholding the direct effects of CO_2 and precipitation at current levels, illustrated in Fig. 4. For example, with +2 °C temperature rise, yields of wheat and soybean increase by 10–15 %, and maize and rice increase about 8 %; however, yields of all four crops turn negative at +4 °C (Downing 1996).

The Impact of Higher Temperature on the Water Available to Agriculture

Agriculture is strongly influenced by the availability of water, and climate change is expected to affect the agricultural process by the changes in temperature, seasonal rainfall, and precipitation patterns, in addition to the expected frequency of floods and droughts especially for rain-fed crops and irrigated crops. Also, higher temperatures are expected to enhance the occurrence of moisture stress due to the accelerated transpiration which is harmful to crops, particularly soybeans and wheat, and as a result, there will be a need to develop crop varieties with greater drought tolerance (Rosenzweig and Daniel 1995).

Fig. 4 Impact of temperature increase on cereal yields



Higher temperatures lead to an increase in evaporation rates and therefore faster cycling of water (Huang et al. 2010). Although global warming is likely to increase rainfall, the net impact of higher temperatures on water availability is a race between higher evapotranspiration (the combined effect of soil evaporation and plant transpiration) and higher precipitation; however, that race is typically won by higher evapotranspiration (Cline 2008). The demand on water for irrigation is projected to rise as more water will be required per acre; accordingly, more energy will be needed to pump water, making the practice of irrigation more expensive (Rosenzweig and Daniel 1995).

The Impact of Higher Temperature on Soil Fertility and Erosion

Higher temperatures are expected to affect the soil, as warmer conditions are likely to speed up the natural decomposition of organic matter affecting the soil fertility. However, this negative effect could be balanced by the higher photosynthetic rates (Parry 1990). Also, warmer conditions are likely to accelerate the continual cycling of plant nutrients (carbon, nitrogen, phosphorus, potassium, and sulfur) in the soil-plant-atmosphere system and thus enhancing greenhouse gas emissions (Rosenzweig and Daniel 1995).

Furthermore, warmer conditions and higher CO_2 will increase the process of nitrogen fixation (nitrogen is made available to plants in a biologically usable form through the action of bacteria in the soil), where drier soil conditions will reduce both root growth and decomposition of organic matter and increase vulnerability to wind erosion. And an expected increase in extreme precipitation events will enhance soil erosion (Rosenzweig and Daniel 1995).

Moreover, higher temperature will accelerate the soil evaporation and hence decrease the soil moisture availability (Cline 2008). Finally, higher temperatures will increase the hazard of salt accumulation in the soil due to the intensified evaporation and evapotranspiration.

Generally, changes in soils (e.g., loss of soil organic matter, leaching of soil nutrients, salinization, and erosion) are a likely consequence of climate change. However, cropping practices such as crop rotation, conservation tillage, and improved nutrient management are very effective in combating or adapting such effects (IPCC 1996).

The Impact of Higher Temperature on Pests and Diseases

The warmer conditions are more favorable for the proliferation of insect pests extending their geographic range. Longer growing seasons will enable insects such as grasshoppers to complete a greater number of reproductive cycles during the spring, summer, and autumn (Parry 1990).

Warmer winter temperatures may also allow larvae to grow over in new areas, as it is now limited by the cold temperatures, thus causing greater infestation during the following crop season. Altered wind patterns may change the spread of both wind-borne pests and bacteria and fungi that are the agents of crop disease. Crop-pest interactions may shift as the timing of development stages in both hosts and pests is altered (Parry 1990).

The possible increases in pest infestations may bring about greater use of chemical pesticides to control them, a situation that will require the further development and application of integrated pest management techniques (Rosenzweig and Daniel 1995).

The Impact of the Enhanced CO_2 Levels on Agriculture

The Impact of the Enhanced CO_2 Levels on the Agricultural Process

Crop production depends mainly on the photosynthesis process that allows plants to absorb energy from the sun, carbon dioxide (CO_2) from the air, and water from the soil, converting them into sugar and cellulose/carbohydrates. Accordingly, the impact of an increased CO_2 level on agriculture is summarized in Fig. 5. Any increase in CO_2 concentrations will immediately increase the photosynthetic rate, allowing more CO_2 to be absorbed and converted to carbohydrates. However, such initial strong response is often reduced under long-term exposure to higher CO_2 levels. Increasing in the rate of photosynthesis will increase the leaf area production, hence earlier and complete light interception, which stimulates biomass, thus increasing respiration. So, the difference between photosynthetic gain and loss of carbohydrate as a result of respiration is the net growth (Fisher et al. 2002). Higher levels of atmospheric CO_2 also induce plants to close the small leaf openings known as "stomata" through which CO_2 is absorbed and water vapor is released by transpiration. Thus, under CO_2 enrichment, the transpiration will decrease and crops will use less water even while they produce more carbohydrates. This dual effect will likely improve water-use efficiency, which is the ratio between crop biomass and the amount of water consumed (Rosenzweig and Daniel 1995).

Moreover, an increase in CO_2 level accelerates crop development due to the increase in leaf temperature resulting from the reduced transpiration and leading to an accelerated aging of the leaf tissue, as well as a faster rate of plant development and therefore a considerable increase in leaf area development, especially in the early crop growth stages. However, the overall effects of leaf-temperature increase will depend upon whether or not optimum temperatures for photosynthesis are approached or exceeded. Moreover, at higher CO_2 levels, plant growth damage caused by air pollutants, such as nitrogen oxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3), is at least partly limited because of the reduced stomata opening (Fisher et al. 2002).

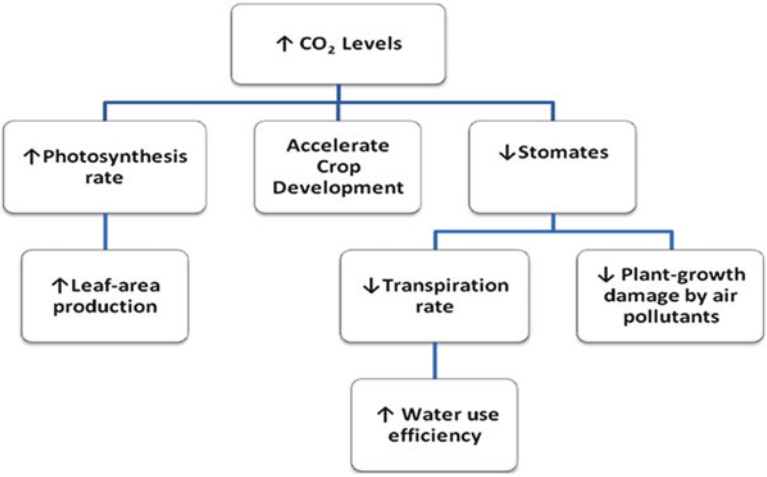


Fig. 5 Impact of enhanced CO_2 levels on agricultural process

Although increased atmospheric concentrations can stimulate photosynthesis and improve the efficiency of water use by plants, the extent to which this happens depends on the type of plant, as crop species vary in their response to CO_2 because of differing photosynthetic mechanisms. CO_2 concentration is known to have more positive effect on C3 crops (C3 crops are so-called because the product of their first biochemical reactions during photosynthesis has three carbon atoms and they belong to a physiological class that responds readily to increased CO_2 levels, e.g., wheat, rice, and soybean) than C4 ones (e.g., corn, maize, millet, sugarcane, and sorghum) that tend to be less responsive to enriched CO_2 concentrations (Stern et al. 2006).

As shown in Fig. 6, C3 plants expected to increase in productivity by about 20–30 % at doubled CO_2 concentrations, while C4 plants show an increase by 5–10 % only which is less pronounced response than that of the C3 crops (Fisher et al. 2002).

The Impact of the Carbon Fertilization Effect on Crop Yields

The impact of climate change on agriculture mainly depends on the size of the "carbon fertilization effect," as carbon dioxide is the basic building block for plant growth. Higher CO_2 concentration is expected to enhance the initial benefits of warming and increase yields through stimulating photosynthesis and decreasing water requirements. Such positive effects was expected to offset the negative ones – as water stress, shorter growing season, and lower yields – raised from increasing the mean temperature (Stern et al. 2006).

Predictions for the carbon fertilization effect suggest that yields of several cereals – wheat and rice in particular – will increase with 2–3 °C temperature

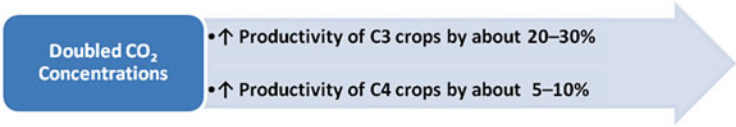


Fig. 6 Impact of doubling CO_2 levels on productivity of cereals

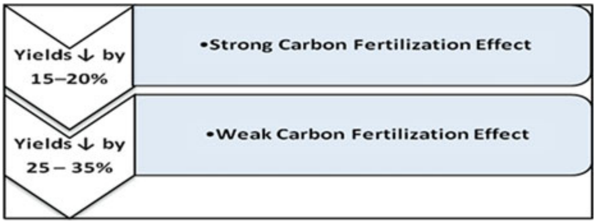


Fig. 7 Percentage yield decrease across Africa and Western Asia (due to temperature increases by 3 or 4 °C)

increase and then starts to fall with greater temperature increases. However, maize shows greater declines in yield with rising temperatures because of its different physiology that makes it less responsive to the direct effects of rising carbon dioxide. And the world cereal production was expected to fall marginally by about 1–2 % only for warming up by 4 °C. Yet, the latest analysis from crops grown in more realistic field conditions suggests that the effect is likely to be more than what previously predicted. That in case of weak carbon fertilization effect, worldwide cereal production is expected to decline by 5 % for a 2 °C rise in temperature and 10 % for a 4 °C rise. By 4 °C, entire regions may be too hot and dry to grow crops. Agricultural collapse across large areas of the world is possible at even higher temperatures (5 or 6 °C); however, clear empirical evidence is still limited. Furthermore, the impact is expected to be strongest across Africa and Western Asia (including the Middle East), illustrated in Fig. 7, where yields could fall by 25–35 % (weak carbon fertilization) or 15–20 % (strong carbon fertilization) once the temperature increases by 3 or 4 °C. Maize-based agriculture in tropical regions – such as parts of Africa and Central America – is expected to be severely declined due to its less responsiveness to carbon effects (Stern et al. 2006).

The carbon fertilization effect becomes obvious when highlighting the expected decrease in the agricultural output capacity, which is predicted to be 3.2 % globally versus 15.9 % if the fertilization effect is not taken into consideration, as mentioned in Fig. 8. Also the developing countries are expected to be highly affected than the industrial ones even if the carbon fertilization effect is taken into consideration (Cline 2007). So the developing countries are expected to be severely affected by the climate change through the reduction in the agricultural yields even if the carbon fertilization effect is considered.

The above impacts of climate change on agriculture indicate that there are interrelated positive and negative impacts for the temperature increase and CO_2 enhancement on agriculture, which could be summarized in Table 2.

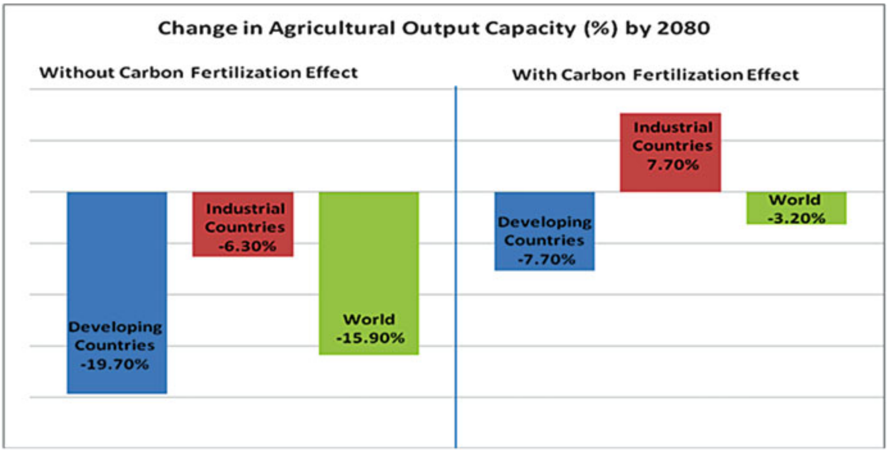


Fig. 8 Expected change in agriculture output by 2080

The above analysis concludes that agriculture is extremely vulnerable to climate change; some tropical low-latitude regions as most of the African and developing countries are projected to be negatively affected by the climate change through the reduction in the available irrigation water, the loss of agriculture land, changes in soil moisture, and increasing pest and disease problems, which would all in all lead to the loss of crops. For example, it is predicted that African countries and some parts in Asia are likely to face 30 % losses in the crop yields by 2080, where the effects of temperature and precipitation changes on crop yields are beyond the inflection point of the beneficial direct effects of CO_2. On the contrary, high-latitude northern countries are expected to benefit from the climate change by extending the growing seasons and decreasing the growing period required for the crop maturation, in addition to augment crop productivity due to the increased photosynthetic activity and improved water-use efficiency as result of the carbon fertilization effect. As well, crop yields in the developed countries are expected to increase as a result of regional increases in precipitation that compensate for the moderate temperature increases and as a result of the direct effects of high concentration of CO_2 (Parry 2004).

The overall effect of moderate climate changes on the world is expected to decrease food production, as reduced production in some areas is balanced by gains in others. Nevertheless, the vulnerability to climate change is greater in developing countries, which in most cases are located in lower warmer latitudes, as cereal grain yields are projected to be negatively affected by the climate change. Hence, agricultural exporters in middle and high latitudes (such as the USA and Canada) stand to gain, as their national production is predicted to expand and particularly if grain supplies are restricted and prices rise. Thus, countries with the lowest income may be the hardest affected (Stern et al. 2006).

Table 2 Positive and negative impacts of climate change on agriculture

Item	Positive impact	Negative impact	Notes/limitations
Impact of enhanced Co_2 concentration levels on agriculture	Increase the photosynthetic rate, and carbon fertilization effect is enhanced	Stimulate biomass	The initial strong response of photosynthetic rate is often reduced under long-term exposure to higher CO_2
	Water-use efficiency will increase as a result of closing stomata	Increase respiration rates	Crop species vary in their response to CO_2 in part due to their photosynthetic mechanisms
	Decrease transpiration rate		CO_2 concentration is known to have more effects on C3 crops than C4 ones
	Accelerate crop development		
	Partly limit the plant growth damage caused by air pollutants		
Impact of higher temperature on agricultural process	Improving the conditions for crop growth as follows:	Accelerates physiological development, leading to hastened maturation and reduced yield	If the temperature exceeds the optimal, crops respond negatively with a great drop in net growth and yield
	Extending the length of the potential growing season	Accelerates the respiration rate	Crop yields respond positively for temperature increases up to 3 °C, after which any further increase will decrease crop yields
	Reducing the growing period required by crops for maturation	Speeds annual crops and allows less grain to be produced	
	Increasing the possibility of completing two or more cropping cycles during the same season	Increases evaporation rates and reduces the moisture availability	
	Crop-producing areas may expand		
Impact of higher temperature on the water available to agriculture	Rainfall increase	Agricultural process; rain-fed and irrigated crops will be affected by the change in the precipitation and rainfall pattern	The evaporation effect of the higher temperature is greater than the rainfall increase
		Causes moisture stress which is harmful to crops	
		Increases evaporation, causing faster water cycling	

Impact of higher temperature on soil fertility and erosion		Speeds the natural decomposition of organic matter affecting soil fertility	Increases in root biomass resulting from higher photosynthesis could offset soil decomposition
		Enhances plant nutrient cycle and increases CO_2 and N_2O gas emissions and leaching of soil nutrients	
		Increases vulnerability of soil erosion, especially with extreme wind and precipitation events	
		Accelerates evapotranspiration rate and decreases soil moisture availability	
		The hazard of salt accumulation in the soil will increase due to intensified evaporation	
Impact of higher temperature on pests and diseases		Increases proliferation of insect pests and hence the greater use of chemical pesticides	
		Extends the geographic range of some insect pests	
		Enables insects to complete a greater number of reproductive cycles	
		Causes greater infestation during the following crop season	
		Altered wind patterns change spread agents of crop disease (wind-borne pests, bacteria, and fungi)	

Correspondingly, given the adverse effects of the climate change on agriculture, the international community and especially the developing countries, which are located in the low warm latitudes and expected to be severely affected by the climate change, should take serious steps toward facing climate effects through mitigation and adaptation methods, in addition to enhancing the international cooperation and activating the related agreements that will be mentioned in the next section.

International Global Climate Change (GCC) Agreements

The overwhelming impacts of climate change raised the call for taking various collective international efforts and agreements as shown in Fig. 9. However, the signature of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 is considered to be the turning point in addressing the climate problem and providing a new focus for the climate-related activities.

Most of the climate change agreements showed an increasing global awareness for the role of the developed countries in assisting the developing ones, based on the principle of "common but differentiated responsibility" that, for example, only ten developed countries are responsible for releasing almost 70 % from the total world greenhouse gases in 2005 (WRI 2012), yet the whole world countries are suffering from the negative impact of these emissions.

Egypt has realized the importance of international cooperation in dealing with climate change. However, as a non-Annex country, it was not committed to meet any specific emission reduction or limitation targets. Accordingly, Egypt is expected to have a more vital and substantial role in tackling the GCC with special concern toward reducing such increasing emissions by enhancing the active integration in the international GCC activities, not only to be committed to the emission reduction but also to make use from other countries' experience in dealing with GCC through various adaptation and mitigation methods.

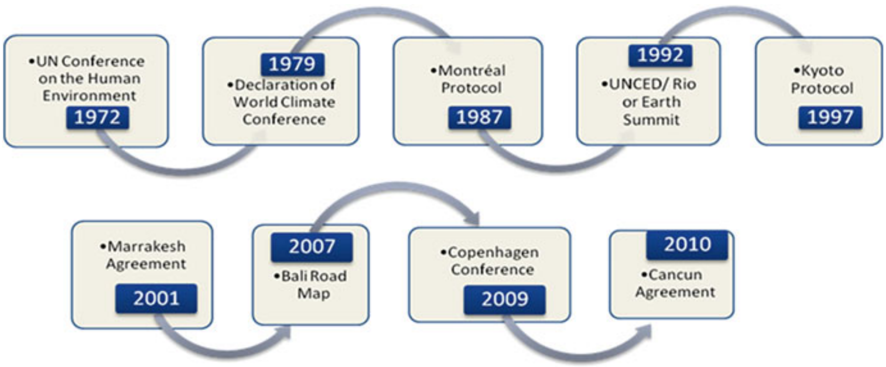


Fig. 9 Major international climate change actions and agreements

The Role of International GCC Agreements

All of GCC international agreement were expected to limit and/or reduce the current levels of the GHG emissions, and hence can be used to measure the impact of these agreements. However, the world GHG emissions have increased by **20 %** during the period from1990 till 2005.

Furthermore, the climate change agreements and especially the UNFCCC and Kyoto Protocol aimed at encouraging the industrialized (Annex I) countries to both reduce their GHG emissions and assist the developing (non-Annex) countries in adapting and mitigating the negative impacts of climate change. However, as shown in Fig. 10, GHG emissions in Annex I countries have been reduced by only 1.5 % from 1990 to 2005, while the emissions of non-Annex countries show an enormous increase of 42 % in 2005 compared to 1990. Moreover, the increasing gap of GHG emissions between Annex I and non-Annex countries indicates the financial and technical capability of Annex I countries to reduce their emissions and use the latest clean and green technologies when compared to non-Annex or developing countries which lack the suitable resources for mitigating the climate change and reducing its emissions.

Accordingly, a special concern should be directed to non-Annex, developing countries that lack technical resources to face the climate change, thus resulting in an enormous increase in their GHG emissions which will expand all over the globe. Therefore, serious international steps should be taken to achieve the objectives of climate change agreements, noting that Annex I countries (i.e. developed countries) should take the lead in combating the climate change by mitigating the climate change, reducing their GHGs emissions, adapting the negative impacts of climate change, and assisting the developing countries to do the same, depending on the principle of common but differentiated responsibilities.

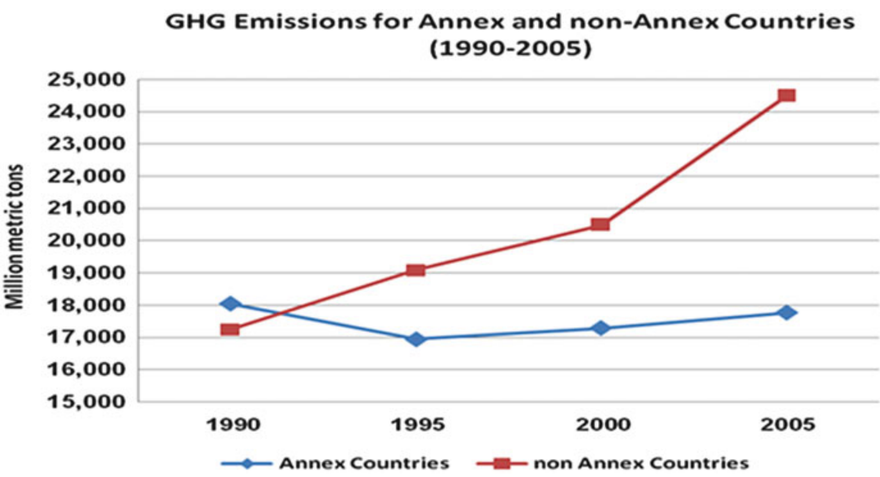


Fig. 10 GHG emissions for Annex and non-Annex countries (1990–2005)

Egyptian Situation Concerning the GCC

Egyptian Contribution in the GCC

Although the total GHG emissions of Egypt are considered minor, representing only 0.53 % of the total world emissions in 2005, these emissions have increased dramatically by around **82 %** in only 15 years as shown in Fig. 11.

Such dramatic increase in the GHG emissions could be explained in the light of several indicators, including the high population growth rates that have also increased by 30.5 % from 1990 till 2005 and the increase in the national energy use by 91.5 % as a result of the expanding consumption of fuel in industry, transportation, and electricity presented in the increase of the energy use per capita during the same duration by 46.5 %.

Figure 12 shows energy sector as the main source of GHG emissions in Egypt by releasing 75 % from the total emissions in 2005 followed by the agricultural sector, industrial process, and waste which release 12 %, 8 %, and 5 % from the total GHG emissions of Egypt in 2005 (WRI 2012).

Accordingly, the agricultural sector is considered to be the second largest emission sector in Egypt. So, mitigation efforts should be directed toward reducing the GHG emissions from this sector parallel with taking the suitable adapting measures toward the climate change consequences in this sector with the highest possible consideration.

Impacts of GCC on Egypt

Egypt is considered to be one of the most vulnerable countries toward the climate change, as its lifeline is concentrated in only 5.5 % from its total area, mainly in the coastal zones and around the Nile, the sole source of freshwater in Egypt. So, any disturbance in the sea level or Nile flow as result of the climate change will

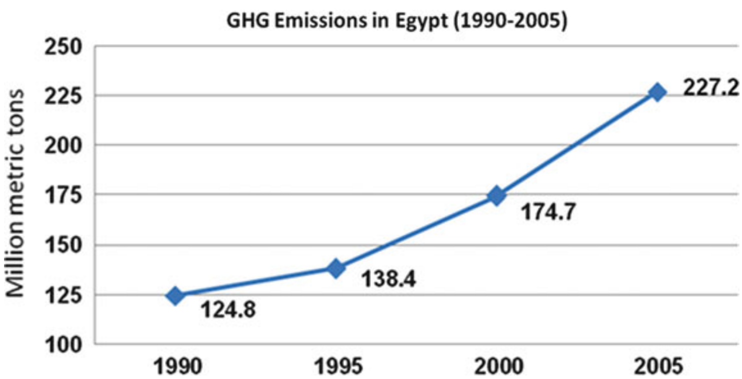


Fig. 11 GHG emissions in Egypt (1990–2005)

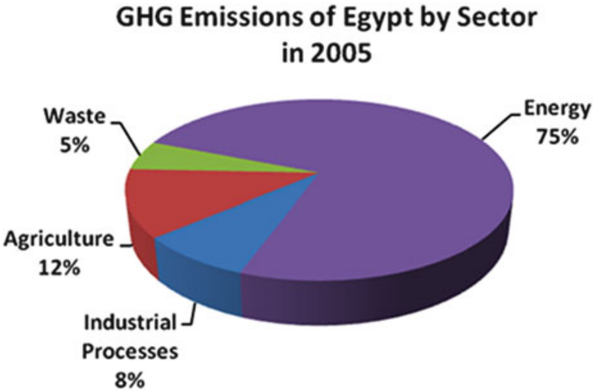


Fig. 12 GHG emissions in Egypt by sector

obviously affect various strategic, economic, and social sectors in Egypt (Saber 2007). One of the most expected sectors to be affected from the climate change is the agricultural sector, which will be affected from both the changes in the temperature and Nile flow, as it consumes 80 % from the total Nile demand and relies mainly on intensive water irrigation (OECD 2004).

Agricultural production is affected in the first place by the overall temperature. Accordingly, temperature increases, disturbances in precipitation, high evaporation rates, elevated CO_2 levels, prevalence of pests and diseases, and other consequences of the climate change will definitely affect the agricultural sector in Egypt. Although Egypt depends currently on importing most of the basic agricultural products to overcome the insufficiency problem of its production against the growing population rates, the problem will be much more complicated when considering that the GCC is expected to increase such insufficiency.

Study by Saber (2007) predicted that the climate change will increase the insufficiency of the agricultural cereal crops by 10–60 % and decrease their productivity by 18 % for wheat and barley, 19 % for maize and sorghum, 28 % for soybean, and 11 % for rice in 2050 which will definitely threaten the food security in Egypt, especially when its related to a strategic crop like wheat. Moreover and based on the expected decline in the productivity, as well as the projected increase in the population rates, the self-sufficiency rates of wheat, maize, and rice are likely to decline by 45.4 %, 80.7 %, and 153 %, respectively, in case of 2–3 °C temperature increase (Noufal 2009). Accordingly, adaptive measures are needed through cultivating different varieties of wheat that can bear high temperatures and show resistance to drought, along with the expansion in cultivating winter crops such as lentils with good distribution of wheat among the geographic areas that are likely to prevent the negative effects of expected or at least reduce the expected negative effects of the climate change (IDSC 2007).

Accordingly, despite the increase that might occur in photosynthetic rates as a result from CO_2 enhancement, climate change is expected to severely affect agricultural sector as whole and from many perspectives as shown in Fig. 13.

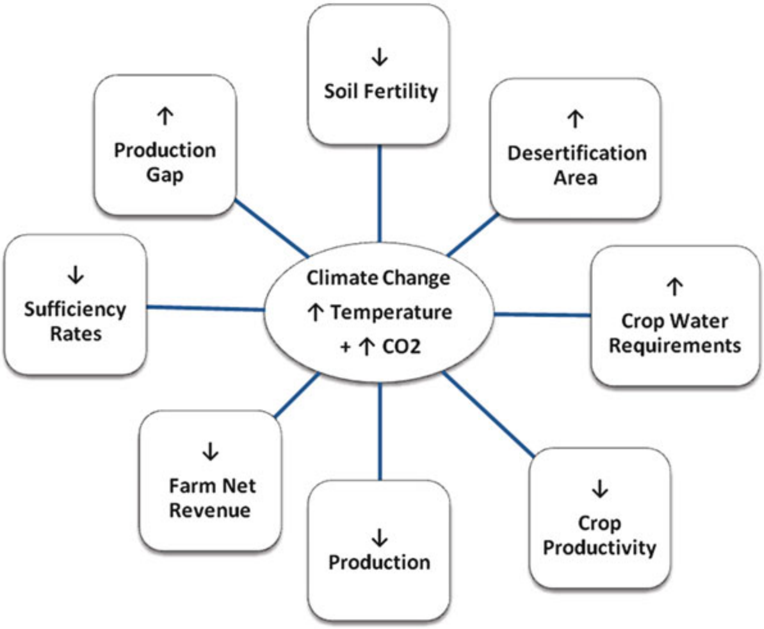


Fig. 13 The impact of GCC on agricultural sector in Egypt

Such consequences will not be limited to the agricultural sector, but it be will be expanded to reach the whole economy, especially when dealing with a strategic sector such as the agricultural one sharing with 17 % from the GDP and 30 % from the total employment in Egypt. Climate change is expected to affect the food availability in general and cereal in specific, affecting both the production in Egypt and in the major exporting countries as well. So, the following section will focus on showing the economic structure of cereals in Egypt to reach a conclusion on how the cereal imports will be affected by the climate change given the expected production decrease of the exporter countries, noting that Egypt is a net importer country for cereals due to its increased insufficiency compared to the increased domestic consumption.

Economic Impact of GCC on Cereal Imports to Egypt

Economic Structure of Cereals in Egypt

Cereals are a strategic agricultural commodity in Egypt as shown in Fig. 14, which have a very special production and trading position. In terms of production, cereals are ranked to be the first agricultural commodity group that shared almost 45 % from the total agricultural cultivated area and 30.8 % from the total agricultural production in 2010. By product, wheat and maize are considered to be the

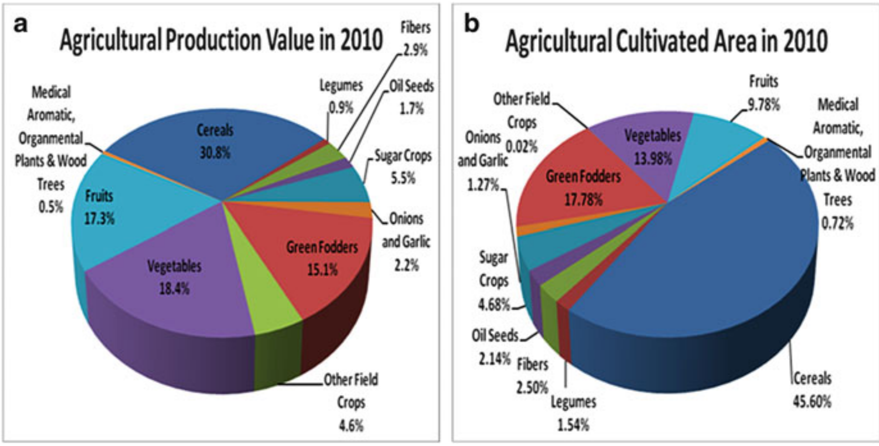


Fig. 14 Agricultural Production and cultivated area in 2010

main cereal crops that shared 78 % from the cultivated area, 73 % from the production value, and 82 % from the average per capita of cereals in 2010, followed by rice, sorghum, and barley, respectively (Ministry of Agriculture and Land Reclamation 2012).

In terms of trade, cereal imports are ranked to be the fifth largest imported products to Egypt, where wheat and maize constituted 63 % and 36 % from the total cereal imports, respectively. Although the cereal imports constitute only 7 % from the total Egyptian imports in 2010, Egypt is considered to be the third largest importing country from cereals generally and the first importing one from wheat specifically (Trade Map 2012).

The trade structure of cereals during the last 15 years has shown that imports were 8 times greater than the exports on average, yet the growth rate of the cereal exports was almost triple the cereal imports during the same period based on Comtrade data, which indicates the continuous active effort of Egypt toward enhancing its trade position by pushing the cereal exports regardless its small share compared to the cereal imports. However, Egypt is considered a net cereal importer country with an increasing trade deficit that jumped by almost 162 % from 1995 till 2010 (Fig. 15). Accordingly, the next section will focus on the cereal imports. It is worth noting that the increase in cereal imports (by $ value) indicates an increase in the cereal import prices rather than the real imported quantity; therefore, this study emphasizes on the cereal import quantities rather than the value ones.

The analysis of the cereal imports per product during the period from 1995 till 2010 shows that wheat and maize constituted the major part and accounted for almost 58 % from the total cereal imports to Egypt, followed by maize with 41 % as shown in Fig. 16.

Accordingly, the remaining sections of this research will focus on wheat and maize, as Egypt is depending on imports to fill its production gap, and hence any decrease in these vital strategic import products, due to climate change, will affect negatively the Egyptian economic and social life.

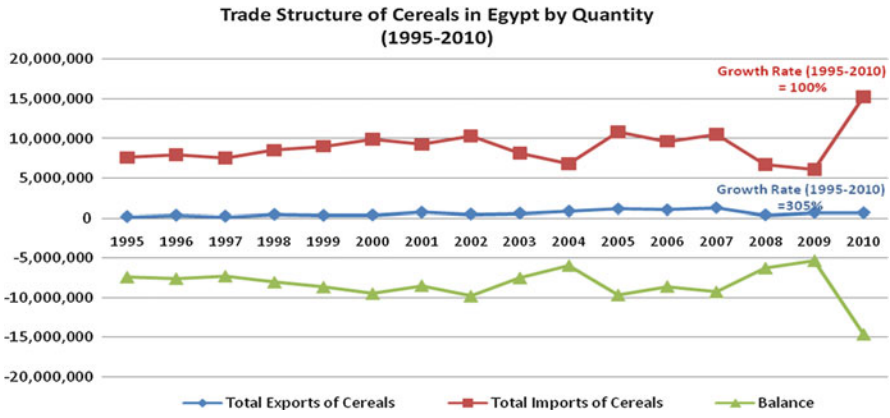


Fig. 15 Trade structure of cereals by quantity (1995–2015)

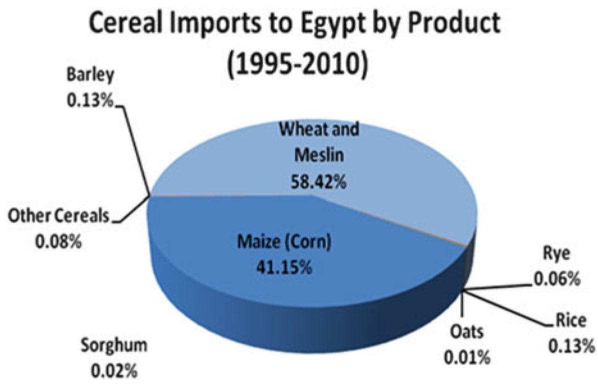


Fig. 16 Cereal imports to Egypt by product

Impact of GCC on Egyptian Imports of Cereals

In order to examine the indirect impact of the GCC on the cereal imports to Egypt, the first step is to identify the direct impact of the GCC on the production of cereals in the major exporting countries to Egypt using a reliable study (Hisas 2011); this will be followed by an econometric model that shows the effect of any production variation in the major exporting countries on the Egyptian imports of cereals and then finally links and shows the impact of the GCC on the cereal imports to Egypt, given the production variations resulted from the GCC.

Accordingly, this section will be divided into the following three subsections:

- Impact of GCC on production of wheat and maize in the major exporting countries
- Impact of production change of wheat and maize in exporting countries on cereal imports to Egypt
- Impact of GCC on Egyptian imports of wheat and maize

Impact of GCC on the Production of Wheat and Maize in the Major Exporting Countries

As mentioned earlier, climate change is expected to amend the geographic distribution of the global agricultural production in favor of higher- and middle-latitude countries (classifications for countries by latitude and world climate map are mentioned in the Annex). A study by Hisas (2011) predicts the impact of the GCC on the food production of different countries for various products in 2020 compared to 2008 based on Parry (2004). In regard to the major wheat exporting countries to Egypt, it indicates that the production of wheat is expected to increase as a result of the GCC in the USA by 10 % and in Russia by 5 % and to decrease in France and Australia by 5 % and 12 %, respectively, while for maize its production is expected to increase in the USA by 10 % and to decrease in Argentina by 5 % and in Ukraine by 10 %. Such expected variation in the production of the largest exporting countries of wheat and maize is likely to disturb the global food security, especially when it is related to a strategic commodity such as wheat. The problem is not limited to these exporting countries but extended to reach those countries which depend mainly on the cereal imports in filling their production gaps like Egypt, as any change in the production is likely to affect international trade as well.

Moreover, the problem is more sophisticated for wheat in specific, as any reduction in this strategic commodity will affect negatively the social and economic life of Egypt, especially when noting that the self-sufficiency of Egypt in wheat was only 40.5 % in 2010, indicating the dependence of Egypt on wheat imports in meeting the growing consumption rates.

Impact of the Production Variations on the Egyptian Cereal Imports

And in order to measure the impact of the production change in exporting countries on Egyptian imports of wheat and maize, a multiple linear regression model (MLRM) is applied for each product and exporting country to Egypt separately with a time series from 1991 till 2011. The four applied models are based and constrained by the availability of data, especially Russia and Argentina which are limited by the unavailability of a complete import data series. The models contain six explanatory variables that affect and shape the Egyptian imports including the production of wheat and maize in the major exporting countries as follows:

$$\begin{aligned}\mathrm{Ln}\left(\mathrm{IMP_{ij}}\right) = \beta 0 + \beta 1\,\mathrm{Ln}\left(\mathrm{C_i}\right) + \beta 2\,\mathrm{Ln}\left(\mathrm{GDP}\right) + \beta 3\,\mathrm{Ln}\left(\mathrm{Prod_{ij}}\right) \\ + \beta 4\,\mathrm{Ln}\left(\mathrm{PR_{ij}}\right) + \beta 5\left(\mathrm{EXCH}\right) + \beta 6\left(\mathrm{FR}\right) + \varepsilon\end{aligned}$$

where

- IMP_{ij} is the Egyptian imports of product i from country j (by quantity)
- C_i is the total consumption of product i in Egypt (by quantity)
- GDP is the real gross domestic product of Egypt
- $Prod_{ij}$ is the total production of product i in country j (by quantity)
- PR_{ij} is the unit import price of product i from country j

Egyptian Imports of Wheat will be affected by:	Production of Wheat in:	The Effect
	USA	+ve
	Russia	neutral
Egyptian Imports of Maize will by affected by:	**Production of Maize in:**	**The Effect**
	USA	-ve
	Argentina	neutral

Fig. 17 Model results by signs

– EXCH is the exchange rate
– FR is the net foreign reserve in Egypt
– ε is the error term

This model has four applications for each crop and country separately. The first is the Egyptian imports of wheat from the USA and then from Russia, followed by another two applications for the Egyptian imports of maize from the USA and then from Argentina, in order to show the impact of the production change in each exporting country on the Egyptian imports of wheat and maize.

By running the model, it shows that the Egyptian imports of wheat are expected to be affected positively by the production change of wheat in the USA and neutral to any production change of wheat in Russia, while, on the other side, the Egyptian imports of maize from the USA are expected to be affected by the production change of maize with a negative relationship and neutral to any production change of maize in Argentina as shown in Fig. 17.

Impact of GCC on Egyptian Cereal Imports (Result Linkages)

By linking the expected impact of the GCC on the production of wheat and maize in the major exporting countries to Egypt that was based on Hisas's study, with the results of the model that analyzed the impact of the production change on the Egyptian imports to Egypt, the impact of the GCC on the Egyptian imports of wheat and maize could be extracted through the expected production variations in the major exporting countries in Fig. 18.

Figure 18 shows that climate change is expected to affect the Egyptian imports of wheat and maize from the USA, while its effect seems to be neutral on the Egyptian imports of wheat from Russia and the imports of maize from Argentina.

Moreover, the effects of the GCC on the Egyptian imports of wheat and maize from the USA are not the same. As though it is positively affecting both wheat and maize production in the USA, it is reflected positively on wheat imports and negatively on the maize imports from the USA to Egypt. This could be recognized in the context of increase in maize consumption in the USA (90 % of its production), compared to the US consumption of wheat (57 % of its production) in 2011 (USDA 2012).

Additionally, despite the expected decrease in the production of maize in Argentina as a result of GCC, no effect was noticed on the Egyptian imports of maize. Perhaps, this is due to its small share in Argentina's total exports. Moreover,

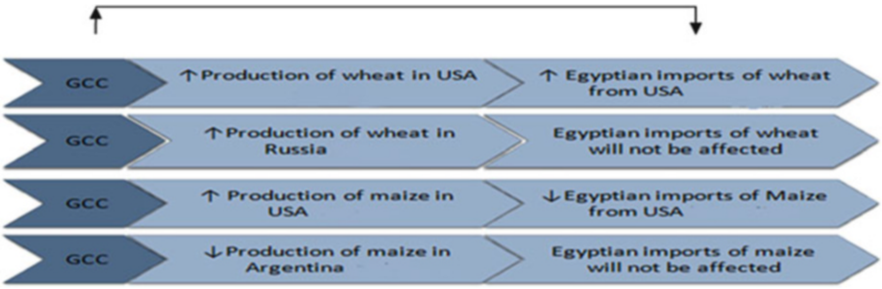


Fig. 18 Results linkages by numbers

no response was observed in the Egyptian imports of wheat from Russia; however, the expected increase in production is due to GCC.

Conclusion

Climate change is one of the greatest environmental problems facing the whole world through its overwhelming adverse impacts across various sectors. Yet, agriculture is expected to be the most affected sector due to its dependency on the overall weather conditions. Impacts of climate change on agriculture vary considerably across different regions, in which the low-latitude countries as most of the African and developing ones are projected to be negatively affected. Agricultural production in general and cereal production in specific are expected to diminish as a result of the increased temperatures and disturbed rain patterns. Egypt, as one of the developing countries, is suffering from a growing insufficiency in cereal production. However, the problem is much more complicated when considering that the climate change is expected to disturb not only the production of cereals in Egypt but also the production of the major exporting countries.

The paper also highlighted the importance of addressing the climate change as a new element in shaping the Egyptian imports. The expected import variations call for the importance of increasing the Egyptian production of wheat and maize by applying the suitable adaptation and mitigation methods, in addition to the import market diversification, in order to prevent the domination of a few countries on the Egyptian imports, especially for strategic commodities such as wheat and maize. This should be applied parallel with taking the impacts of climate change into consideration by targeting the potential countries that are expected to be positively affected from the climate change, such as the USA and Canada.

Finally, this study recommends applying different production methods that aim at mitigating the GCC, in order to reduce GHG emissions, such as efficient usage of energy in transportation, buildings, and industry; switching to zero- or low-carbon energy technologies; improving waste management; reducing deforestation; and improving land and farming management practices. Such mitigation efforts should also be accompanied by adaption ones that aim at diminishing the negative impacts of climate change or to exploit its potential benefits such as using alternative varieties of crops to adapt with the increased temperature, shifting the planting dates, changing fertilizer applications, and building flood controls.

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Part II

Policy and Climate Change

Adaptation to Climate Change in Cities

Magali Dreyfus

Contents

Abstract

Urbanization and climate change are two current significant trends of the Earth's history. Both influence one another. Given the increasing disastrous impacts of global warming, it is vital to understand their development and interaction.

The concentration of people, infrastructures, and economic activities in urban areas contributes to the global growth of greenhouse gas emissions. But it also makes cities particularly vulnerable to the impacts of climate change. Yet many opportunities lie within the powers held by local governments. In fact, through their sectoral policies (land-use planning, transport, buildings, energy use, waste management, etc.), city governments can develop efficient strategies to mitigate and adapt to the effects of global warming. Adaptation strategies are especially

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important as they allow connecting local needs with global concerns. The governance structure of the city and the capacity of the different stakeholders to collaborate in the definition and implementation of adaptation plans are therefore essential to ensure that local actions are efficient.

This chapter presents the implications of climate change in urban environments and the challenges it raises in terms of adaptation policies. It provides illustrations of responses adopted at the city level and points out at the barriers and opportunities faced by local policy-makers.

Keywords
Adaptation • Cities • Climate change • Local governance

Introduction

Urbanization and climate change are two of the few certain global trends for the future. Both raise economic, social, and environmental issues (Moensch et al. 2011). The study of their development and interaction is therefore key for enhancing scientific knowledge and taking action to promote a sustainable future.

Since the mid-2000s, about half of the world population lives in cities, and it is expected that by 2050, this number will raise to 7 out of 10 people (UN 2011; UNHABITAT 2012). One century ago, only 2 people out of 10 were living in urban areas. Moreover, in the past, urbanization went faster in industrialized countries than in developing countries. Nowadays it is the opposite. Today about 70 % of urban residents live in developing countries, which are also hosts to an overwhelming proportion of the world population (82 %). In richer nations, urban population growth is close to stagnant (0.67 % on an annual average basis since 2010). The United States has the highest urbanization rate among these countries (nearly 1 %). But developing countries are projected to have urban growth rates that are roughly the double. Moreover, the number of so-called megacities, which represents urban centers with more than 10 million people, is also increasing. They were 9 in 2008 and they should be 27 in 2025 (UN 2011; Corfee-Morlot et al. 2009). These impressive numbers have an impact on climate change adaptation as well as the well-being of its citizens, in terms of education, housing, and access to services.

Yet there is no standard definition of what a city is, and it may differ largely from one academic discipline to another. For instance, legal scholars and statisticians will often pay attention to the administrative borders of settlements and to the powers held by local governments over these. But a geographer may have a different territorial approach and focus on interconnections that sometimes overtake the formal limits of a settlement. One definition of the city is that it is a geographically limited area, which hosts a high density of population in a densely built environment. It is argued that cities are the results of a surplus in food production. This surplus allowed people to engage in other activities than agriculture and to produce goods as well as services outside of rural areas (Puppim et al. 2012). Thus, cities became key units in the economic welfare of a country.

Some estimates say that urban-based economic activities account for up to 55 % of gross national product (GNP) in low-income countries, 73 % in middle-income countries, and 85 % in high-income countries (Kessides 2000).

Consequently the development of cities has an impact over climate change. Through the concentration of economic activities and production, urban areas are responsible for the consumption of most of the world's energy, and 60–80 % of world energy use emanates from them (IEA 2008; Corfee-Morlot et al. 2009). They are therefore directly as well as indirectly among the largest emitters of CO_2 emissions. On the other way round, climate change impacts may be worsened by the urban settings. This led some commentators to declare that "the fate of the Earth's climate is intrinsically linked to how our cities develop over the coming decades" (Tyndall Centre 2004).

All the more, urban settlements are heavily dependent on what is produced outside their limits, may that be the nearest countryside or the products imported from farther countries. There climate change impacts may have important consequences. It may affect water and land availability, and thus local and global agricultural production, raising the prices of the products. Moreover, rural land in the peripheries is now often dedicated to urban use. As a result a common phenomenon in developed and developing countries is the growth of low-density-based suburbanization (UNHABITAT 2012). Sustainable cities must therefore be thought outside of their administrative and urban borders. This chapter sets aside this complex rural–urban issue and focuses on urban areas, but this is an important issue to bear in mind.

Policy-makers have a direct interest in climate change issues because urban areas are directly and particularly vulnerable to its impacts. In particular adaptation has to be thought locally as it requires taking into account the impacts of climate change on the local territory and the elements of vulnerability (physical, socioeconomic) upon which actions may be taken (Corfee-Morlot et al. 2011). In fact local governments are best placed to provide efficient solutions. Early in 1987, the Brundtland Report on "our common future" included a chapter on cities underlying their importance to design solutions to promote sustainable development (WCED 1987; Betsill and Bulkeley 2006). Then in 1992 during the United Nations Conference on Environment and Development (UNCED) held in Rio, the role of local authorities in meeting global environmental goals was fully recognized and included in Agenda 21, the United Nations (UN) voluntary action plan to promote sustainable development (Bulkeley and Betsill 2003). Lately scholars have slowly turned their attention to them to draw out barriers and opportunities for urban settlements in coping with climate change. They point out that cities concentrate resources and constitute "pools of labour and talent, together with concentration efficiencies for both producers and consumers, and a more fluid exchange of ideas and innovations" (UNHABITAT 2010). The IPCC itself in its fourth Assessment Report acknowledges the role of the cities. In particular, local governments hold responsibilities in sectors, which are relevant to the definition and implementation of mitigation and adaptation strategies. These vary from one state to another and depend on the level of decentralization. They are, for instance, transport, energy, waste, water, land-use planning, and social services. Moreover, local governments are the closest institutional link to the citizens and therefore may be in touch with a wide variety of stakeholders who can help define locally tailored solutions to the climate problem. Finally cities are important economic actors in the national economy, and as such they also have an influence on the definition of national policies and may act as a "role model" for other public authorities.

This chapter first examines the contribution of the cities to global warming (section "Contribution of the Cities to Climate Change") and the impacts of climate change that they bear (section "Impacts of Climate Change and Vulnerability of the Cities"). Then it shows how activities have moved focus from mitigation to adaptation (section "From Mitigation to Adaptation") and examples of some adaptation strategies (section "Urban Adaptation Actions"). Subsequently it dwells on the important questions of urban adaptation's governance (section "Governance of Adaptation in the Cities") and the barriers faced by decision-makers to adopt or implement adaptation strategies (section "Barriers to Cities' Adaptation to Climate Change"). Then in conclusion, three kinds of strategies highlighting potential opportunities for the future are presented.

Contribution of the Cities to Climate Change

The contribution of cities to climate change is highly debated.

Some authors reckon that they have an important share of responsibility, as they are heavy emitters of greenhouse gas (GHG) emissions. Some estimate show that urban activities generate close to 80 % of all carbon dioxide (CO_2) as well as significant amounts of other greenhouse gases. Direct sources of greenhouse gas emissions include energy generation, vehicles, industry, and the burning of fossil fuels and biomass in households. Emissions from vehicles and transport equipment are rising at a rate of 2.5 % each year (UNEP-UN HABITAT 2005). Moreover cities consume two-thirds of total primary energy and produce over 70 % of global energy-related CO_2 emissions. The IEA projects predict that by 2030, as a result of increased urbanization, cities and towns will be responsible for 76 % of global energy-related CO_2 emissions (IEA 2009).

But other studies discuss these findings (Hoornweg et al. 2011; Dodman 2009; Satterthwaite 2008). Some reckon that the actual share of GHG emissions generated in the cities is 40 %. Satterthwaite has described this phenomenon very well. The main source of greenhouse gas emissions in cities is energy use – in industrial production, transport, as well as residential, commercial, and government buildings (heating or cooling, lighting, and appliances). Transport is also an important contributor to greenhouse gas emissions in almost all cities, although its relative contribution varies a lot from one city to another. But the emission profile varies from one city to another depending on their activities as well as on their design and governance. A dense built environment and the use of public transport in a big city may result in lower emissions than in a smaller city where the use of private

Table 1 Greenhouse gas emissions per capita (tons of CO_2 equivalent)

City	GHG emissions per capita (tons of CO_2eq) (year of study in brackets)
Washington, DC (USA)	19,7 (2005)
Glasgow (UK)	8,4 (2004)
Toronto (Canada)	8,2 (2001)
Shanghai (China)	8,1 (1998)
New York City (USA)	7,1 (2005)
Beijing (China)	6,9 (1998)
London (UK)	6,2 (2006)
Tokyo (Japan)	4,8 (1998)
Seoul (Republic of Korea)	3,8 (1998)
Barcelona (Spain)	3,4 (1996)
Rio de Janeiro (Brazil)	2,3 (1998)
Sao Paulo (Brazil)	2,1 (2003)

Source: Dodman 2009

vehicles is more important because of the urban sprawl. For instance, as Table 1 shows, Tokyo's emissions per capita are much lower than in Glasgow, although the latter is smaller in size and population (36,669,000 inhabitants in urban agglomeration in 2010 and 1,170,000, respectively (UNHABITAT 2012)). Even within one urban area, the household's socio-demographic characteristics influence energy use. As a result, a suburban space may have, on average, higher per capita residential energy consumption with respect to central city dwellers (Estiri 2012).

Moreover, places with large coal-fired power stations will be very high greenhouse gas emitters, although most of the electricity they generate may be used elsewhere (Satterthwaite 2008). So a central question is whether greenhouse gas emissions used in producing goods or services are allocated to production or consumption. As a producer of GHG emissions, cities are not necessarily heavy emitters, but if emissions are assigned to the final consumer's home, most emissions from agriculture, deforestation, and industry could be assigned to cities where the goods produced from these sectors are consumed. Moreover, a comparison between energy use in urban and rural areas seems to show that with economic growth, city dwellers tend to consume more and more energy. Krey and others studied urban and rural energy use patterns in China and India functions of three development models that they have defined. On this basis, they show that in most cases, per capita energy use is initially lower in urban areas compared to rural areas, due to higher shares of modern fuels, which are energy efficient. But economic growth shall reverse that trend, and by 2050, urban energy use per capita will have tripled with respect to 2005 (Krey et al. 2012).

This might have important consequences in defining responsibilities for reducing greenhouse gas emissions between nations and within nations between cities and other settlements. Therefore, in the end, an important step to address climate change is to assess the consumption patterns of middle- and upper-income groups within an area (Satterthwaite 2008).

Impacts of Climate Change and Vulnerability of the Cities

Direct impacts of climate change are various, and all of them may affect cities: increased intensity and higher frequency of disasters (storms, rainfall, and typhoons), sea-level rise, and draughts. Indirect impacts will also be born at the local level such as the arrival of refugees fleeing the impacts of climate change or new diseases caused by the apparition of new vectors.

As everywhere, climate change will worsen existing problems as well as creating new ones. But some impacts will be stronger or specific to the urban environment (see Table 2 below).

Then the vulnerability of a city, that is, its ability to withstand direct and indirect impacts, depends on of three factors: its exposure, its sensitivity, and its adaptive capacity.

Table 2 Climate change impacts on urban areas

Change in climate	Possible impact on urban areas
Changes in means	
Temperature	Increase in energy demands for heating/cooling
	Worsening of air quality
	High-temperature impacts exaggerated by urban heat islands in the cities
Precipitation	Increased risks of flooding
	Increased risks of landslides
	Distress migration from rural areas
	Interruption of flood supply networks
Sea-level rise	Coastal flooding
	Reduced income from agriculture and tourism
	Salinization of water sources
Changes in extreme	
Extreme rainfall	Damages to home, businesses, and infrastructures
Tropical cyclone	More intense flooding
	Higher risk of landslides
	Disruption to livelihoods and city economies
Drought	Water shortage
	Higher food prices
	Disruption of hydroelectricity
	Distress migration from rural areas
Heat or cold waves	Short-term increase in energy demands for heating/cooling
	Health impacts on vulnerable populations
Abrupt climate change	Possible significant impacts from rapid and extreme sea-level rise/ temperature change
Changes in exposure	
Population movements	Movements from stressed rural habitats
Biological changes	New disease vectors

Source: Adapted from Bartlett et al. (2009)

In a city, physical elements (infrastructure and ecosystems), agents (people, organizations, and administrative and elected bodies), and institutions (the rule that guide behavior) (Moensch et al. 2011) may be more or less exposed, sensitive, or capable of adapting.

Exposure is the nature and degree to which a system may be directly or indirectly exposed to climate conditions such as temperature changes, rainfall variability, and change in extremes and frequency of other hazards (Moensch et al. 2011). Sensitivity is the degree to which a system is affected, either adversely or beneficially by climate variability (IPCC 2007). Indeed the concentration of people and economic activities make cities more likely to bear greater impacts. And the adaptive capacity is the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007). It can also be described as the ability to shift strategies as conditions change in order to maintain the well-being of populations and ecosystems on which they depend (Moensch et al. 2011).

Typically cities are exposed because they are located in strategic areas such as near the coasts or rivers. Thus, they suffer particularly from sea-level rise and floods. Moreover, cities concentrate a lot of people, and in many countries, the poorest of them live in informal settlements, slums, and townships. This is especially true for developing countries where the urban growth rate is the highest. As it goes faster than the infrastructure capacity, these settlements are very sensitive and their capacity to recover is limited. These are especially vulnerable, as they tend to be built on hazardous sites and to be susceptible to floods, landslides, and other climate-related disasters (IPCC 2007).

Although exposure is strong, the vulnerability of the cities mostly lies on their sensitivity and low adaptive capacity. In particular as seen above, the urban poor are the most vulnerable population to climate change impacts (Corfee-Morlot et al. 2009). Sensitivity is high and adaptive capacity is low among marginalized populations (slum-dwellers, recent migrants, women, etc.) as they are often unable to access or use effectively the services provided in the cities (Moensch et al. 2011).

Moreover, institutions affect vulnerability as they determine how other dimensions are managed (provision of essential services, infrastructure investments, zoning regulations, social assistance, etc.) (Moensch et al. 2011). In least developed countries, these may be weak.

Finally as mentioned in introduction, the vulnerability of the cities cannot be fully detached from its surroundings as climate change may affect food production or transport systems causing an increase in price and thus affecting the lives of citizens.

Urban areas are affected by three kinds of change caused by climate change (Bartlett et al. 2009): changes in means, changes in extreme, and changes in exposure. In the first category lie temperature, precipitation, and sea-level rise. In the second one stand extreme rainfall and tropical cyclone, droughts, heat or cold waves, and abrupt climate changes. Finally the last category refers to migration of population and biological changes.

The impacts of climate change may be exaggerated by the urban setting. A notorious illustration of this phenomenon is the urban heat island (UHI) effect.

It refers to the temperatures of urban centers, which are higher than in the surroundings of the city (about 3–4°C and this can go up to 10°C). The built environment, impervious surface, and lack of vegetation impede the soil to moisture, which would normally use the absorbed sunlight to evaporate water. The UHI in turn affects the level of air pollution as warmer temperatures favor the concentration of conventional air pollutants such as ozone, acid aerosols, emissions of particles, and allergens (Corfee-Morlot et al. 2009). The health of vulnerable populations such as young children and older people is then even more at threat than in a common hot environment.

All these impacts ultimately result in health impacts such as infectious diseases transmitted by mosquitos or tick, water- or food-borne diseases, air pollution, and heat morbidity (Bartlett et al. 2009). In addition the impacts have an economic cost. Some assets and infrastructures may be lost and economic activities may be disrupted. Structures such as underground transport systems may be affected by weather disaster events (Hunt and Watkiss 2010). For instance, during the heat wave that hit Europe in 2003, many French cities suffered from high temperatures. Electricity demand increased with the high heat levels, but electricity production was undermined by the facts that the temperature of rivers rose, reducing the cooling efficiency of thermal power plants (conventional and nuclear), and that flows of rivers were diminished. As a result, six power plants were shut down completely (IPCC 2007), which resulted in economic losses for utility companies and individuals.

From Mitigation to Adaptation

Mitigation policies aim at reducing GHG emissions in order to curb climate change at the global level. Adaptation tends to minimize the effects of climate change by adjusting the systems; it also allows grabbing any opportunity, which may arise. Adaptation activities have a local nature. They are largely determined by local circumstances such as the physical and built infrastructures environment, by the perception of vulnerability and risks by citizens and policy-makers, or even by a long history of dealing with natural hazards and disasters (Satterthwaite 2008; D'Almeida Martins and da Costa Ferreira 2011).

But mostly because cities are considered to be heavy emitters, literature has focused on urban mitigation actions so far.

Moreover, mitigation activities have found important financial support and thus became profit-making actions for local governments. These financial flows originate for instance in the United Nations Framework Convention of Climate Change (UNFCCC) international regime, which binds the most industrialized states to curb their GHG emissions. To do so, they can implement projects such as clean development mechanism (CDM) or emission reduction certifications (CER) in countries which are not bound by any emissions target. Obligations on adaptation are limited to financial and technical assistance from industrialized countries to the lesser-industrialized nations.

In that context, most of the climate city plans focus on mitigation and only a few deals with adaptation (OECD 2009). Many cities have assigned themselves GHG emissions reduction targets (e.g., London, Tokyo, and Paris). Some go even further than the national target. For instance, in the European Union and in France, the targets are 20 % for the reduction of GHG emissions, 20 % less energy consumption, and a 20 % energy consumption coming from renewable energy by 2020. But for the Parisian territory, the local council targets a rate of 25 % (and for the administration itself 30 %). This leads to a general phenomenon of well-developed mitigation project, whereas adaptation policies are still at an early stage of development and hardly implemented (D'Almeida Martins and da Costa Ferreira 2011).

Some authors have criticized this focus on mitigation stating that it is too techno-centric and falls to address the more complex task of defining the nature of vulnerability (Revi 2008). But the difficulty to quantify and monetarize the benefits of adaptation, makes it difficult for decision-makers to justify their choices when they develop adaption strategies. How do you measure the success of an adaptation measure? And how long does it take before you can actually make an assessment? In fact most of the studies assessing adaptation policies options in the cities are qualitative (Hunt and Watkiss 2010).

However, the case for adaptation in the cities in literature is increasing. The importance of this action is recognized. Among the studies, Hunt and Watkiss (2010) have observed that the most addressed risks are sea-level rise, heat, and water resources. Yet to date most of the case studies deal with OECD countries. This is why international agencies now try to promote adaptation through development as a way to incentivize actions in less developed countries (OECD 2009; Sanchez-Rodriguez 2009; UNEP 2011).

The following section turns on some of these initiatives.

Urban Adaptation Actions

Adaptation actions are not always labeled as such nor are they systematically connected to the issue of climate change. This could be the case for instance, for urban environmental projects such as planting trees or the opening of green spaces. However, these actions definitely have an adaptive scope. Moreover, the variety of administrative organization between cities also complicates the possibility to classify actions by sector. They may be overlapping. Therefore, it is difficult to make an exhaustive list of adaptation actions. Before summarizing some of them in a table, here are some more developed examples.

First there are some hard measures meaning that they require some financial and technological investments. For instance, in the building sector, local governments have power to take action.

Isolation of buildings is a key activity for local governments. It allows bringing down temperature and reducing the need for air conditioners. Thus, energy demands and consequently emissions are reduced. This is a much more efficient adaptive measure than the mere spreading of air conditioner appliances which might not be affordable for the poorest and which will be counter-effective in terms of mitigation (OECD 2009).

Harvesting of rainwater can also offset the lack of water in hot summers. In London, a rainwater harvesting system has been incorporated in the design of a community center building. The rainwater is collected from the roof and is stored in an underground tank for future use. This system is supplying water used for toilet flushing and irrigation. It is expected to contribute to save 50 % of water use every year (UKCIP 2007).

Bigger infrastructures may also be necessary. Infrastructures and the built environment in general are mostly affected by extreme events such as floods, storms, and, to a lesser extent, heat waves and drought (Hunt and Watkiss 2010). The construction of flood defense mechanisms, dikes, or break walls is a common response. However, it is a high investment operation, and local governments may not always have the financial resources and technical capacities to undertake these operations.

Softer measures are also efficient to define adaptation strategies. They consist in policy programs. A common measure is to move the location of activities (recreational, farming, and businesses) set in high-risk areas (flood/erosion prone areas) to safer places. To do so, local governments usually use regulatory instruments such as zoning regulations or master plans.

The table below (Table 3) presents some adaptation action functions of the climate challenge they want to tackle. The columns also indicate the sector of intervention and the nature of the corresponding policy instrument. However, this table is only illustrative. Cities are very much different from one place to another in political, economical, social, and physical terms. As a result, the decisions they take vary to adapt to local circumstances. Likewise the sectors and policy instruments are different. As for sectors, the department of a city responsible for a certain matter may differ from one place to another.

There are several kinds of policy instruments, which may support adaptation strategies. They can be combined to ensure a better efficiency. Regulatory tools are binding measures, which fix environmental targets or standards to be reached by some stakeholders. They can also consist in provisions and technical requirements in public procurements. To that regard, local authorities as a major buyer of public works, infrastructures, and constructions may follow a green approach to favor environmentally friendly projects (e.g., climate change may fall within the scope of the environmental, energy, or land use department).

Planning tools are regulatory instruments. Planning is a political process, which organizes the completion of predefined political goals in time. It helps in dealing with uncertainty of future risks relying mainly on data from the past and present and the analysis of trends. It states which policy instruments are going to be used and fix a calendar. Fiscal mechanisms are financial incentives and disincentives to guide behavior towards environmentally responsible activity, and curb undesirable activities, in an effort to reduce damage to the environment. They consist in grants, low-interest loans, loan guarantees, or favorable tax treatment to promote specific activities, technologies, or behaviors of businesses and individuals. For example, in

Table 3 Examples of adaptation actions in cities

Climate challenge	Measure	Sector	Policy instruments
Urban heat island	Increasing tree canopy	Parks, environment	Regulatory
Heat waves	Reforestation		Planning
	Green roofs	Buildings and construction	Regulatory Fiscal Voluntary agreements
	Building regulations (e.g., color of the roofs, standards of energy efficiency)	Buildings and construction	Regulatory
	District cooling through the use of absorption cooling methods (using the heat of other resources, e.g., waste incineration)	Energy	Regulatory Planning
	Heat alert systems	Public health	Informational instruments
	Heat threat educational and awareness program	Education	Informational instruments
Drought Water efficiency	Building regulations (e.g., installation of rainwater collection systems, reservoirs, promote the use of water-efficient technologies and devices)	Building and construction	Regulatory
	Building retrofitting (e.g., shower timers and shower heads)	Water Environment	Informational
	Securing drinking water resources (e.g., designation of drinking water protection areas and well construction)	Water Environment	Regulatory
Biodiversity loss	Biodiversity strategy to protect flora and fauna	Environment Green spaces Tourism and leisure	Regulatory Planning
Floods Sea-level rise	Flood risk mapping	Flood/coastal management Disaster management Urban planning	Regulatory Planning
	Flood alert systems	Flood/coastal management Disaster management	Informational
	Dikes, break waves	Infrastructures Build environment and construction	Regulatory Planning
Crosscutting adaptation issues	Vulnerability assessments and development of blueprints or scenarios to guide local stakeholders	Crosscutting	Planning

Source: Adapted from Ecologic Institute, AEA, ICLEI, REC 2011 mitigation policies, charges are levied on energy sources and fossil fuels. Informational instruments are campaigns or public announcements to inform and communicate with the citizens on risks, to learn to deal with them, and to be resilient. Finally voluntary agreements are measures, which are negotiated between local authorities and industry to achieve environmental targets.

In the end, the table shows that adaptation strategies are based on a mix of soft (policy) and hard (infrastructures and built environment) measures.

Some actions address physical drivers such as dikes and built protection infrastructures, and others address systemic drivers such as laws, urban planning, alert warning systems, or efforts to build capacity to adapt (CorfeeMorlot et al. 2011).

Governance of Adaptation in the Cities

Listing initiatives to adapt to climate change in urban settings is not enough to get a complete picture of the challenge that it represents. In fact sectoral approaches are not enough and a systemic approach is necessary. It means that several administrative departments and stakeholders have to collaborate with one another. Moreover, climate change impacts are not limited to the administrative territory borders, so often collaboration is needed beyond borders, between local governments. Finally upper levels of governments have some adaptation programs and regulations. They may ask local governments to collaborate to implement them. There is therefore a huge governance[1] challenge.

Urban governance processes are actually central to understand the impacts of climate change and to reduce vulnerability. Good governance schemes allow working closely with local stakeholders and understanding how to incorporate climate change impacts in the reform of land use and urban planning instruments. It also gives the possibility to experiment and learn about various responses and the most cost-efficient ones (Corfee-Morlot et al. 2011, D'Almeida Martins and da Costa Ferreira 2011).

Literature has often focused on governance to identify successful factors for adaptation (Tanner et al. 2009; Birkmann et al. 2010; Adger et al. 2005; Amundsen et al. 2010; Dodman and Satterthwaite 2008). They also drew some good governance GG criteria, which enable developing efficient adaptation strategies. GG criteria and adaptive criteria are often redundant. These criteria vary according to authors and often overlap according to their definition. Referring to GG in the framework of enhancing resilience, Moensch et al. (2011) mention decentralization and autonomy, transparency and accountability, and responsiveness and flexibility (Tanner et al. 2009). Other scholars add participation and consensus, effectiveness

[1]Governance refers to "the formation and stewardship of the formal and informal rules that regulate the public realm, the arena in which state as well as economic and societal actors interact to make decisions" (Hyden et al. 2003).

and sustainability, and rule of law, equity, and fairness (Dreyfus 2013). For Adger et al. (2005), adaptation shall rely on effectiveness, efficiency, equity, and legitimacy.

Almost all authors acknowledge participation as a major success criterion. It refers to the degree of involvement of the different stakeholders in decision-making. It is key to understand all the risks, define adaptation objectives, and ensure a good implementation of the measures adopted. The roles of stakeholders are numerous: awareness raising, involvement in understanding the problem, agreeing adaptation objectives, securing financial and human resources, implementation, as well as monitoring and evaluation (Ecologic Institute et al. 2011).

Leadership is another relevant factor at the local level (Ecologic Institute et al. 2011, Schreurs 2008). It is illustrated by the important adaptation strategies developed by some proactive local governments. Being a pioneer can be positive in political terms but also even in economic terms by creating new business opportunities. Sometimes single individuals or "policy entrepreneur" can champion the issue and, this way, adjust the local agenda to include it (Bulkeley 2010).

Moreover, in their analysis, scholars insist on the need to adopt a multilevel governance approach (Betsill and Bulkeley 2006; Corfee-Morlot et al. 2009). This refers to the processes of governance happening across the scales, formally or informally, between state and non-state actors and between public and private actors. Participation is a central process of it. This conceptual approach helps to understand how local governments are embedded in a complex system of actors and how they design and implement policies tackling climate change. Thus, there is a vertical and a horizontal dimension to consider. The vertical dimension focuses on a legal traditional approach where local governments are at the bottom of the state administrative organization and where the central government possesses the supreme authority. Here local governments mostly implement upper level of legislation (international, national, state, or regional). The horizontal dimension focuses on various actors intervening at the city scale: citizens, associations, business actors, and transitional networks of local governments, foreign investors, and experts. In that context, local governments are responsible for defining policies relevant to the local affairs. Relations between them are not necessarily formalized, and they are constantly evolving. Their influence over one another very much depends on the local context (Puppim et al. 2012). This approach allows identifying bottom-up, top-down, and horizontal influences, all of them playing a part in the definition and implementation of adaptation strategies.

Barriers to Cities' Adaptation to Climate Change

There are some conceptual barriers and some practical barriers to adaptation (Ecologic Institute et al. 2011). Conceptual barriers relate to the understanding of the problem. It consists in climate skepticism, uncertainty, and defining what is adaptation. This mostly affects decision-making. It can be overcome by the involvement of external actors such as researchers or international agencies with an interest in the question. Transnational networks of local governments are also helpful, as they allow knowledge and best practice sharing between public authorities.

Practical barriers are more related to organization and resources. They mostly affect the implementation of adaptation strategies.

Adapting to climate change is a long-term process, which as such is not a priority for local governments who have to deal with many other pressing issues, such as the eradication of poverty, public services provision, and development. The uncertainty of climate scenarios and its controversial aspect (some scientists denying its scope) makes it a second rank issue. Uncertainty is also true for socioeconomic trends, which affect the vulnerability of population and activities. Yet this information is as important as climate data. Moreover, analyses of impacts and adaptation options at the city-scale level are at a very early stage and difficult to provide in poorer countries. There is a lack of tools and methodologies to inform decision-makers about risks exposure, which is a main barrier for adaptation decisions in land-use planning (Storch and Downes 2011). Most of the studies are qualitative, and thus, the advance understanding of costs and benefits of local adaptation action is difficult (Hunt and Watkiss 2010; OECD 2009). Yet the making up of climate and urban development combined scenarios could be very profitable. A study on Ho Chi Minh City adaptation strategy shows that the combination of sea-level rise with the planned urban development will increase the exposure and consequently the vulnerability of the city. But it is mostly because of the second factor, which is the land-use plan, that the city will be affected. The decision-makers have not considered exposure and climate risks in the plan (Storch and Downes 2011). Indeed climate change impacts cannot be avoided, but prohibiting constructions on threatened areas can reduce exposure. This will allow avoiding at a later stage the costs of relocation, reconstruction, and disaster relief action. Nevertheless pressed by short public mandate, local governments sometimes focus on policies that can bring more immediate results.

The lack of resources is another major issue. Despite the political will or the adoption of a strategy, the question of financial as well as human resources is a limit. This is therefore sometimes a problem, which precedes issues such as the lack of access to sophisticated datasets or new technologies (Roberts 2010). When there is no support from national authorities, resources may come from external actors. In fact many adaptation programs in developing countries are sponsored from outside, by the World Bank, UN-HABITAT, or UNDP for instence. But then the question is how these initiatives will carry on after the withdrawal of this external funding. There may also be a problem of overlapping competencies and lack of coordination between authorities and policies. As Table 3 shows, initiatives may be shared between various sectors and use different policy instruments. This makes coordination a key step.

Conclusion: Opportunities for Climate Change Adaptation in the Cities

In conclusion, three tracks can provide opportunities for climate change adaptation in the cities.

Adopt a Comprehensive Strategy for the Local Territory

Adopting a comprehensive adaptation strategy will allow defining policy direction for the entire city. It is important because no single measure will allow reducing vulnerability on a long term basis. It is rather a set of different cross-sectoral actions that will allow to improve the current and future situations. A mix of policy measures, technologic, institutional, infrastructure, is necessary. Cities must in fact be thought as a system (Dawson et al. 2007).

It means that cooperation between various administrative departments is essential. Planning is a key process to organize this cooperation.

Creating a specific agency or unit in charge of dealing with adaptation issues may also be useful. It may then identify synergies between sectors. This institution can develop knowledge and expertise between the sectors and lead the policies and organize the cooperation.

So far, only a few general municipal adaptation plans have been adopted. Most of them are in cities of industrialized countries as, for instance, New York or London. But there are some exceptions in developing countries as Durban, Cape Town, Ho Chi Minh, or Quito demonstrate. The motivations behind the adoption of municipal plans lie in the need to assess local impacts carefully and ensure resilience. In Ho Chi Minh, a particular objective is to put in line hard infrastructure responses with a socioeconomic vulnerability assessment of the city (Storch and Downes 2011). In Durban, the need to adapt is perceived in relation with the need to increase the resilience of poorer people by enforcing measures enabling development (Roberts 2010).

Moreover, in compliance with the UNFCCC regime, adaptation in least developed countries is supported financially and technically by industrialized countries as well as by some international agencies. One requirement is to adopt a National Adaptation Programme of Actions (NAPA), which identify priority activities. However, in these programs, little attention has been paid to the local level and urban areas. The adoption of Local Adaptation Programme of Actions (LAPA) and City Adaptation Programme of Actions (CAPA) could be helpful. On the long term, they can underpin and drive innovations in NAPAs (Moser and Satterthwaite 2008).

Use Local Capacities and Share Knowledge

Instead of creating new programs and plans, for which officers may be reluctant to act, it may be worth relying on existing capacities.

A lot of local governments already have experience with planning and environment. For instance, local Agenda 21, which deals with sustainable development, has created an enabling context for environmental issues (Bulkeley 2010; D'Almeida Martins and da Costa Ferreira 2011).

Also synergies between disaster risk management and climate change adaptation can be found. In the more exposed cities, there is often a long and old practice of risk management.

Moreover, using local capacities means enhancing participation of the various urban stakeholders. This enhances knowledge about the local context and the necessary adherence for implementation. There should be therefore a collaborative approach to decision-making when dealing with adaptation (OECD 2009; D'Almeida Martins and da Costa Ferreira 2011).

For instance, in London and New York, the involvement of sectoral stakeholders is deemed to have been key in defining responses to climate change impacts. They created coordinating bodies including sectoral and cross-sectoral representatives who spread in different sector the general policy directions and the results of consultation and studies (Hunt and Watkiss 2010).

In particular the most vulnerable people in the cities need to be heard. As shown in introduction, cities from developing countries are growing very fast. Their population grows more rapidly than their financial, organizational, and infrastructure capacity. Decision-makers are therefore faced with a big number of informal settlements exposed to disasters. Helping the poorest community may therefore increase resilience. It has been observed in developing countries that partnerships between poor communities and local governments focusing on development and tackling risks helped to increase their incomes and thus to reduce health effects of hazards (Satterthwaite et al. 2007). In line with this reasoning, authors promote community-based adaptation (CBA).[2] It is a process which put people at the center of the adaptive strategy. Through learning and development, the poorest appear to increase their resilience and anticipatory capacity.

Sharing knowledge with peers is another good way to highlight potential local capacities. It creates conditions to be inspired and to inspire other local governments who may be faced with the same challenges and constraints. Literature has demonstrated how being part of a network may foster or even be a catalyst in the development of a strategy. Moreover, these networks mobilize also private actors, especially from the business side (e.g., ICLEI's Cites for Climate Protection) (Bulkeley 2010).

Finally, it is important that local governments find support form upper levels of governments which often dictate the norms to implement and the distribution of resources. Central governments should therefore acknowledge the role played by local authorities and consider it the definition of national adaptation strategy. On this basis, they may then provide financial support.

Mainstream Climate Change Adaptation

Mainstreaming climate change adaptation in sectoral policies means considering the impacts of climate change in each sector and providing adapted solutions.

[2]According to CBA, it is "an approach that is putting people in the centre of their own development, by facilitating a learning process that increases resilience and anticipatory capacity. It is not just a response to climate events and shocks, but rather a complex and holistic process that includes personal development and organizational development to ensure an enhanced problem solving capacity, and the capacity to anticipate events and plant so that future shocks are buffered" (Koelle and Annecke 2011).

A general adaptation strategy is important to raise awareness and may be catalyst in considering climate change impacts, but it needs to be trickled down in the sectors.

In Durban, the local government adopted a general adaptation strategy in 2006. But it did not bring any result until some sectors were chosen to further develop an adaptation program, i.e., health, water, and disaster management (Roberts 2010). In fact within local governments, administrative departments are more or well developed, have more or less resources, or even have already undertaken initiatives regarding climate change. On this basis, some departments may be able to adopt more ambitious and efficient strategies.

In that framework, the general adaptation strategy will be an umbrella avoiding contradictory sectoral policy objectives and ensuring coherence. This will also achieve multiple goals (not only mitigation and adaptation targets) (Schreurs 2008).

In particular, mainstreaming climate change adaptation within development programs can prove very efficient. People with higher education level, training, and access to services are less vulnerable. Decision-makers must therefore engage in the development of win-win scenarios, that is, policies, which achieve both adaptation and other development goals.

Decisions taken today will determine the future development path of the city. Yet how cities develop is part of the climate problem but also the solution. Choices regarding long-lived infrastructures (transport networks, buildings, ports, and water systems) are decisive to improve the energy and emission of the built environment as well as to determine their capacity to resist future climate disasters. Also land use and zoning decisions are important to increase or limit the exposure and vulnerability or urban dwellers and activities to climate hazards. It is therefore vital to integrate now climate change impacts and risks in the decision-making process. Combined with socioeconomic data and development policies, it will enable cities to develop in a sustainable manner for the benefit of the local as well as the global environment.

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Assessing the Capacity of Law to Facilitate Adaptation to Climate Change

Margot A. Hurlbert

Contents

Abstract

Certainty of law is an important attribute in a democratic society; however, often certainty is synonymous with inflexible, traditional laws, perhaps no longer appropriate in times of rapid social, geographical, and natural system change. Institutional capacity to adapt to climate change has been shown to be a key determinant of adaptive capacity; law is a foundational institution of socio-environmental regimes. Appropriate provisions are required in law in order to ensure that the institution of law can adapt to future variability and extreme climate events of drought and flood. Law must facilitate adaptive governance and reflect principles of adaptive law.

Laws and their mechanisms (regulatory, economic, and suasive instruments) can reduce exposure or vulnerability thereby building capacity to respond to anticipated increasing future variability in extreme climate events. However, there is also the possibility that the opposite impact may occur, and laws impede adaptation. This chapter explores this tension.

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This chapter focuses on an assessment of laws and legal mechanisms to improve adaptive capacity of rural agricultural producers to respond to climate variability and change. Legal instruments in relation to water, specifically the property interest in water, impact rural agricultural producers. A comparative assessment of three legal water tools (market, common property, and public property) impacting vulnerability in relation to extreme events of drought and flood is conducted, and conclusions are made on their ability to assist adaptation.

Keywords
Law • Policy • Adaptation to climate change and extreme climate events • Adaptive law

Introduction

This chapter will focus on institutions in relation to adaptive capacity and more specifically the institution of law in relation to the natural resource of water. This chapter will focus on the market or economic interest – the property interest of water because of the important relationship of the area of water to climate change, adaptation, and vulnerability (UNWATER 2010). A brief discussion of institutions and law and adaptive capacity will be followed by an outline of adaptive governance and adaptive law, a description of the possible tools relating to the property interest of water (market, common property, or public property), and an analysis of how these three possible tools reflect (or do not reflect) the principles of adaptive law and governance. This chapter will conclude with proposals to improve the adaptive capacity of law in relation to the legal instrument, the property interest of water.

Law, Institutions, and Adaptive Capacity

Law is a formal institution (Luhmann 2004, p. 59), a set of rules defining roles and procedures for people determining what is appropriate and proper. As such, law is an important component of the institutional system which contributes to the adaptive capacity of communities. The IPCC argues that nations with "well developed institutional systems are considered to have greater adaptive capacity" and that developed countries have a better "institutional capacity to help deal with risks associated with future climate change" (2001, pp. 896 and 897). Institutions contribute to the management of a community's assets, the community members' interrelationships, and then in turn their relationships with natural resources. Law plays a fundamental role in this regard, especially in relation to defining the relationship of people to one another in respect to access to, caring for, and sharing natural resources. Law establishes the legal rules of property ownership or licensed access to many natural resources such as forests, water, wildlife, and minerals. Law also sets the framework for which organization, levels of government, government departments, or ministries have authority over, establish conflicts in relation to, and protect natural systems and the socioeconomic relationships corresponding to these systems.

This is not to say that law is the only or predominant institution contributing to the adaptive capacity of communities. Vulnerability to climate change impacts is also determined on the basis of the degree of climatic change experienced by a region or community and a combination of the geophysical processes and other existent social conditions (Birkmann 2006; Hilhorst 2004). Other institutions in addition to law contribute to adaptive capacity including formal institutions like government, nonprofit and civil society organizations, and informal institutions such as social norms, values, and contexts which contribute to the relationships of people to each other and natural resources. Further, in addition to these institutions, other determinants of the adaptive capacity of people and communities which determine their ability to respond to, create, and/or shape vulnerability and change (Chapin et al. 2009) exist. These additional determinants of adaptive capacity include the existence of economic resources, infrastructure, and equity, as well as access to technology, information, and skills (including human capital) (IPCC 2001, p. 893).

Studying the institutional context of adaptive capacity can be done through a study of the institutions involved in governance. Governance encompasses laws, regulations, and institutions, as well as governmental policies and actions, domestic activities, and networks of influence, including international market forces, the private sector, and civil society (Demetropoulou et al. 2010, p. 341). Governance entails the interactions among structures, processes, rules, and traditions that determine how people in societies make decisions and share power, exercise responsibility, and ensure accountability (Lebel et al. 2006; Raik and Decker 2007; Cundill and Fabricius 2010, p. 14). Thus, governance involves institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their legal obligations, and mediate their differences (Armitage et al. 2009; Kiparsky et al. 2012). Law is an important institution, operating within the wider institutional context of governance. A rich literature has developed regarding adaptive governance, adaptive water governance, and specifically how the wider institutional context of governance can facilitate adaptation and improve adaptive capacity of communities. As law is an important component of this institutional context (one institution within the institutional context, as it were), this literature is instructive and informative in respect of the consideration of whether law has capacity or whether a better capacity of law can be developed, to facilitate adaptation.

Adaptive Water Governance and Law

How do we recognize a system of water governance as adaptive? Within the adaptive capacity literature, several dimensions have been identified as important characteristics, institutional design principles, or features of governance systems that define an institutional system as adaptive. These include such things as "availability of information," "openness for experimentation," "flexibility," "learning," and others. The discussion in some cases is generic, and it applies to institutions in general (Gupta et al. 2010; Folke et al. 2005; Gunderson and Holling 2002; Olsson et al. 2006) and in some other cases to specific institutional regimes, such as the case of water governance (Moellenkamp and Kastens 2009; Huntjens et al. 2012; Young 2010; Cook et al. 2011; Hill 2012a; Huitema et al. 2009).

The number of dimensions of adaptive institutional capacity tends to vary depending on the author and the institutional context upon which the discussion is focused. They range from a few characteristics, such as the six dimensions listed in the work of Gupta et al. (2010), to a long suite of attributes, as those identified by Cook et al. (2011), who list fifteen attributes. Frohlich and Knieling (2013) in their discussion of climate change governance offer another set of attributes that should also be considered in a discussion of adaptive governance. They refer to a proper understanding of the complexities of the phenomenon of climate change, which include the requirements imposed by boundaries, levels, sectors, and diverse stakeholders, as well as the uncertainties surrounding and long-term time frame of climate change. A table outlining these various dimensions appears below (Table 1).

Adaptive governance entails more flexible, participatory, experimental, collaborative, and learning-based designs and approaches to policy making and governance to increase the adaptive capacity of institutions and sustainability of natural resources (Pahl-Wostl 2010; Pahl-Wostl 2007a, b; Cromwell et al. 2007; Pahl-Wostl 2007a, b, c; Kallis et al. 2006; Tompkins and Adger 2004; Lee and Lawrence 1986; Walters 1986; Walters and Holling 1990). Adaptive governance shifts focus from rule-based, fixed organization to a view of institutions as dynamic, flexible, pluralistic, and adaptive in order to cope with present and future uncertain climatic conditions and the limits of predictability (IISD 2006, p. 5; Carpenter and Gunderson 2001; Levin 1999). Adaptive governance is then a means to the achievement of adaptive capacity (Cook et al. 2011, p. 7) or combating the loss of resiliency (Berkes and Folke 1998, p. 262). An example of adaptive governance is the comanagement of a natural resource such as water in a cooperative fashion by government, community, and stakeholder groups in a cooperative way through local watershed groups, larger basin groups, and regional and national associations.

The last institutional design principle, that of clearly defined boundaries and rules, relates most directly to the institution of law. A primary function of the legal system is accountability, creating rules, and holding people and entities accountable in relation to these rules. Designing the standards and boundaries to which people and entities are held accountable significantly impacts adaptive capacity and vulnerability. The example cited relates to institutional responses in the event of extreme climate events of flood. However, this last design principle is on its face, quite contradictory to many of the other design principles of responsiveness and flexibility, which have been demonstrated as important for the ongoing management of natural resources in the face of climate change and variability. Balancing the institutional design principles to context is key.

Table 1 Institutional design principles of adaptive governance

	Institutional design principle of adaptive governance	Related principles/sub-principles	Explanation	Literature
1	Responsiveness		The ability of governance networks, organizations, and actors to respond appropriately and in a timely manner to climate variability, hazards, and extreme events in a manner that accounts for ecosystem dynamics	Hatfield-Dodds et al. 2007; Kjaer 2004; Dietz et al. 2003
		Robust and flexible process	Institutions and policy processes that continue to work satisfactorily when confronted with social and physical challenges but which at the same time are capable of changing	Huntjens et al. 2012, p. 73; Moellenkamp and Kastens 2009
	Example		An example of responsiveness is the Saskatchewan Farm Ranch Infrastructure Program which was developed by local agricultural producers in South Western Saskatchewan within weeks of a severe drought in order to provide funds for water infrastructure to producers within days of application. The program was amended on an ongoing basis	Hurlbert forthcoming
2	Variety of problem frames		Openness to multiple frames of reference, opinions, and problem definitions offering a diversity of sometimes competing solutions and options to assess a problem as well as resolve conflict	Gupta et al. 2010
		Multilevel – redundancy	A variety of problem frames inherently involve the participation of a variety of different actors, levels of government, and sectors in the governance process and collective choice arrangements, without redundant overlapping costly systems	Huntjens et al. 2012
		Polycentric governance	Different centers of management and control should exist (as opposed to hierarchical systems)	Ostrom 2010
		Sectoral integration	Adaptation requires an integrated sectoral response so institutional arrangements which are similar or related can be adjusted to one another	Moellenkamp and Kastens 2009
	Example		In the 2001 drought in southern Alberta, water users along the South Saskatchewan River Basin were able to respond within days by exchanging water interests allowing a few agricultural irrigators to produce crops and the needs of local communities to be met. This water sharing involved local people and communities, irrigation associations, agricultural producers and provincial personnel, all with various issues and policy frames	Hurlbert 2011

(*continued*)

Table 1 (continued)

	Institutional design principle of adaptive governance	Related principles/sub-principles	Explanation	Literature
3	Learning and institutional memory		Past experiences must be remembered and learned from and routines improved	Huntjens et al. 2012; Gupta et al. 2010; Armitage 2005; Olsson et al. 2004; Pretty 2003; Dietz et al. 2003; Pretty and Ward 2001
		Participation	Participation by non-state actors	Folke et al. 2005
		Collective choice arrangements	To enhance participation of those involved in making decisions about the system in how to adapt	Huntjens et al. 2012
		Monitor and evaluate	Institutional evaluation processes must monitor and evaluate policy experiences	Huntjens et al. 2012
	Example		Wildlife and watershed comanagement allows for learning and institutional memory by involving stakeholders through planning and informational meetings. These stakeholders participate in monitoring programs focusing on aquatic resources by setting priorities, enhancing their own capacity, monitoring the physical resource, sharing information, and local decision making. These methods have been employed in community forestry projects as well	Tidball and Krasny 2007; CCMN 2008; Fernandez-Gimenez et al. 2008
4	Trust		Institutional patterns must exist to promote mutual respect and trust such that participants continue involvement in the process of governance	
		Open to uncertainty/ open to experimentation	Policy experiments allow feedback loops so policy can be changed quickly in response to changed conditions	Moellenkamp and Karstens 2009
		Constructive conflict resolution	Timely response to problems, careful sequencing, transparency	Huntjens et al. 2012
	Example		The incorporation of participatory processes into the management of a dam in the German Dhuenn basin allowed for policy experiments to occur, uncertainties to be handled in a constructive manner, and a level of trust to be built between participants	Moellenkamp et al. 2010

5	Capacity building	Information	The informational, human, and social capital must exist within the governance regime necessary to respond appropriately to climate variability, hazards, and extreme events	Gupta et al. 2010; Olsson et al. 2004
		Leadership	Leadership must exist to act as a catalyst to change	
		Resources	Appropriate resources (financial, political, human) must be available for this change	
		Information	Rigorous up-to-date information, sufficient and reliable	Moellenkamp and Kastens 2009
	Example		A World Wildlife Fund intervention in the Great Ruaha River catchment in Tanzania addressed challenges from natural resource use and climate variability in changing water resource management by applying participatory methods. The project resulted in rural livelihoods becoming more profitable and water sustainable by diversifying livelihood strategies. The leadership and resources provided were a catalyst for capacity building within the community	Kahaigili et al. 2009
6	Equity	Legitimate	The governance regime must be perceived as legitimate and accountable, as well as fair in its process and impact such that there is an equal and fair (re)distribution of risks, benefits, and costs	Gupta et al. 2010; Huntjens et al. 2012; Ostrom 2011
		Accountable		
		Fair		
	Example		An example of an inequitable regime is the water governance regime in Chile that consists of a water market wherein all water is fully allocated, owned privately, and traded. This has resulted in a system completely within the private sphere, outside the purview of government, in which the courts determine disputes and in which many local communities are without access to water	Hurlbert and Diaz 2013
7	Political support		Responding to climate change is a long-term policy challenge which requires solid political support for plans longer than election cycles	Moellenkamp and Kastens 2009
	Example		Often climate change strategies are dependent on political strategy and subject to election cycles. However, long-term planning for mitigation and adaptation to climate change into 2020 and beyond is required	Hurlbert and Diaz 2013
8	Clearly defined boundaries		Clarity over who has rights and who has responsibility, capacities, access to resources, and information in times of climate events	Huntjens et al. 2012
	Example		In times of extreme climate, such as floods, the response of communities, nonprofit organizations, and governments require clarity in roles, tasks, and responsibilities; there must also be access to reliable and up-to-date information about future conditions; lastly, access to resources such as food, clothing, and aid is essential	

Adapted from Hurlbert and Diaz 2013

One of the fundamental pillars of the law is legal certainty (Maxeiner 2008). Internationally recognized as a central requirement for the rule of law, rule-based societies are required in the interest of legal certainty and predictability (Maxeiner 2008). Law is generally regarded in a positivist fashion as a set of rules reflected in the wording of legislation and decisions of judges all forming a code binding on subsequent legal subjects (Luhmann 2004). In system-theoretical terms, law is an operatively closed network of communications which constantly refers to its own decisions, expressly based in turn on legal principles and procedures. This rigidity and certainty of law appears contradictory to the institutional flexibility envisioned in institutional adaptive capacity and adaptive governance. Reform is difficult because of legal principles such as res judicata and collateral estoppel that ensure finality of legal issues (Arnold and Gunderson 2013), organizational bureaucracy resistant to change (Lazarus 2004), and the goal of law to provide stable contexts within which other social systems (banking, health care, etc.) can operate (Ruhl 2012).

A body of literature is emerging, focusing specifically on features that would characterize an "adaptive legal system" or "adaptive law" (Arnold and Gunderson 2013). This literature overlaps with the adaptive governance and adaptive management literature with many of the suggested design principles of an adaptive legal system replicating that of an adaptive governance system. Common principles include those of communication, monitoring and intermediaries, accounting for scale (Garmestani et al. 2013), polycentric systems, iterative feedback loops (Arnold and Gunderson 2013). In fact, often the recommendation is that adaptive governance could be incorporated into formal legal frameworks (Garmestani et al. 2013).

Utilizing examples from the United States, Arnold and Gunderson (2013) illustrate features of the US legal system which are maladaptive. Legal goals are narrow, focusing on the resilience of the legal system itself or economic goals at the expense of ecosystems and other social institutions including local communities, diverse cultures, etc. Further, legal reform giving primacy to ecosystems or biodiversity may produce unintended consequences including non-implementation, under-implementation, or political backlash. Citing numerous examples of this maladaptive conflicts, the authors find that for law to be adaptive, it must build and strengthen the adaptive capacity of multiple institutions just as it builds and strengthens the adaptive capacity of multiple ecosystems including stimulating the valuation of ecosystem services, strong participatory and deliberative governance of local communities adapting to extreme weather events, rising coastlines, and other environmental transformations. Focusing on goals, structures, methods, and processes, Arnold and Gunderson develop a comparison of features of maladaptive law and adaptive law (Table 2):

> Changing the focus of law from uni-central to a polycentric focus by focusing on policies, methods and tools with co-benefits is cited as another requirement of changing laws from being maladaptive to adaptive. This would allow experimentation and innovation in governance and management, by enhancing participation, encouraging democratization, and risk diversification. The polycentric approach is better matched to scales, scope and speed of problems that arise in a socio-environmental context matching decisions to local norms, culture, and politics. Examples of this are cited as large-scale ecosystem restoration projects or interstate river commissions. (Arnold and Gunderson 2013, p. 13)

Table 2 Comparison of features of maladaptive law and adaptive law

Feature	Maladaptive law	Adaptive law
Goals	Legal regimes aim to advance particular stability of single systems. Current regimes focus primarily on political and economic goals. Alternative (reform) regimes focus primarily on ecological goals	Legal regimes aim for multiple forms of resilience: the resilience and adaptive capacity of both social and ecological systems, including constituent subsystems, such as institutions and communities
Structure	Law is monocentric, utilizing fragmented and unimodal responses to problems	Law is polycentric, utilizing multimodal and multiscalar responses to problems that are loosely integrated
Methods	Law controls society through rules, limits on action and authority, demand for certainty, and legal abstractions that resist change	Law facilitates social and ecological resilience through moderate/evolutionary adaptation to changing conditions, context-regarding standards, tolerance for uncertainty, and flexible discretionary decision making
Processes	Law presumes rational, linear decision making and implementation processes by a single authority and the centrality of law to the ordering and management of human affairs	Law recognizes and embraces iterative processes with feedback loops among multiple participants, limits to human and organizational rationality, and the effects of social and ecological forces on the ordering and management of human affairs, and accountability mechanisms for the conservation of capital

Arnold and Gunderson 2013, p. 5

In conflict with established legal norms (predetermined legal pathways consisting of rigid rules and conventional planning requirements; certainty and security in resources and social structures; preference for risk, liability, and mistake avoidance; decision making based on universally applicable legal abstractions), new methods of law are required. These new methods would facilitate adaptive management methods focusing on learning processes and continuous experimentation. To do so, legal institutions will need to allow private property rights to evolve to changing conditions. Existing legal systems favor human development and use of resources, lands even if adversely affected by climate change, and government-funded infrastructure to facilitate development and compensate property owners for losses. Certain aspects of property law are maladaptive as they are antievolutionary and elevate artificial legal constructs and abstractions that are ill matched to the ecological and social realities that law is intended to address. A context-regarding concept of property as a "web of interests" as opposed to a "bundle of rights" would facilitate the interconnected social and ecological conditions in which property issues arise and impacts of various property alternatives for communities, social systems, and ecosystems (Arnold 2002).

Lastly, it is necessary to understand legal processes not as linear conflicts but in a more complex reality of the law, society and nature relationship. Decisions are made by courts or tribunals, which impact the environment and socioeconomic systems, and over time new decisions, new laws, and findings are made. This interrelationship can be tracked over time and thought of as feedback loops allowing evaluation of impacts with are maladaptive or adaptive. In fact the legal system itself could develop and improve its own feedback loops to evaluate the impacts of decisions and actions (Arnold and Gunderson 2013, p. 21). One suggestion is termed reforming administrative law from "front-end" systems to "back-end" systems where agencies would not have to make all decisions at the outset, the issuance of regulations, license, or permit; instead adaptive management practices would allow adjustments to regulation and changes to permits/licenses via deadline extensions, exceptions, waivers, or variances (Garmestani et al. 2013).

How the apparent conflict of clearly defined rules, boundaries and certainty of laws and the ideas of adaptive law, flexibility, and responsiveness are reconciled and balanced will be outlined in relation to a property interest in water. First, the various permutations of the property interest in water will be discussed followed by a discussion of how this legal instrument, which requires certainty, can be made to be more adaptive.

The Property Interest in Water

There are three major alternatives to the property interest of water. Generally these models relate to the bundle of property rights associated with water, i.e., whether it is owned privately (as a saleable interest as in Chile), as public property (freely available to all), or common property (owned by the water users). In Canada, because the Crown owns all water and water rights are allocated by license, this property ownership distinction is not applicable; however, the property distinction is illustrative as parallels can be seen in the characteristics of bundles of water rights received by way of water license. Based on the three models of property rights, the three institutional models are:

- Government agency management, generally associated with water regarded as public property – government defers its authority for the management of water to an agency which assumes authority for directing who does, and does not, receive water rights in accordance with bureaucratic policies and procedures. In Canada, water is owned by the state (or Crown) and interests are allocated by license. Often a first in time, first in right priority scheme applies (Hurlbert 2009b).
- User-based management, generally associated with water regarded as common property – water users, or those with license or rights to water, join together and coordinate their actions in managing water resources. Decision making is collective among users. Irrigation associations are an example of this type of ownership; another example would be comanaged water resources (Plummer 2009).
- Market, generally associated with water owned as private property – water is allocated and reallocated through private transactions. Users can trade water rights through short-term or long-term agreements or temporary or permanent transfers, reallocating rights in response to prices (Bruns and Meinzen-Dick 1995).

Sometimes a combination of these property interests exists. Alberta has led the provinces in Canada in the development of a water market where transfer of water rights is allowed in accordance with an approved water management plan or by Cabinet order in the absence of such a plan. However, water continues to be owned by the Crown, a license granted to property owners in respect of a parcel of land and then transferred with the land. However, it is possible to transfer a water interest. In the South Saskatchewan River Basin in Alberta, for example, there is a South Saskatchewan Basin Water Management plan which allows the Director to consider applications to transfer water allocations within the basin. The market-based management model employed by Alberta is not a true laissez faire market with vendors and purchasers conducting transactions purely based on market rules; a certain amount of oversight is retained in the review of these transactions and, as such, the predictability of a market model reduced somewhat (Hurlbert 2009b).

Chile changed from having water as public property to private property in 1981 by enacting a Water Code that took place in 2005 (Bauer 2004; Carruthers 2001). Water rights were separated from the land, and a new registry was developed allowing trades without land sales. Permanent water rights exist at an expressed volume per time granted within the guaranteed flows of the water body; however, many other water rights also exist. For example, continuous rights allow withdrawal 24 h a day throughout the year; discontinuous rights can only be used during predetermined periods; and eventual rights can be granted if the flow is above a certain average (Articles 12–18 Water Code).

Of the three property interests in water, private, common, and public, which model is the most conducive to facilitating adaptation and building the adaptive capacity of people and communities?

Analysis of the Property Interest in Water: Adaptive or Maladaptive?

The private property interest in water is thought to be a solution to the more efficient allocation and pricing of water. The statutory provisions allowing transfer are touted by some researchers, and the Alberta government, as advancing the goals of efficient allocation of water interests and conservation in encouraging the transfer of surplus interests. This process is also described as creating a non-regulatory method of reducing wasteful use by creating an incentive to save water and transfer its marginal value for compensation (Percy 2004). The Chilean private property interest in water has contributed to the country's economic development and allowed the state ability to finance a number of public services and infrastructural investments relating to water (Hill 2012a). In Alberta, the ability to transfer a water interest has been allowed and irrigators have done so when facing drought. This has allowed the transfer of a water interest for money and resulting assignment of water to higher value crops yet allowing transferors some financial compensation for the reallocation of their water interest (Hurlbert 2009a).

The private property interest in water fulfills the institutional design principle six of adaptive governance in creating clearly defined boundaries and rules; however, the flexibility of managing the water resource would intuitively be compromised as the government would no longer have a role in managing the resource, guarding ecological limits, and resolving conflicts over water (this being now the realm of legal courts). Many would argue the market tool does not capture the community value of water, nor does it facilitate political and ethical considerations in allocation decisions. The risk of the market is that impacts on third parties not party to a market transaction are neglected, and third parties have difficulty enforcing their interests in a court of law. Although the design principle of "certainty of rules" (8) is achieved, the property interest in water operates a maladaptive legal goal aimed at advancing the stability of a particular system, the market.

It is noteworthy that some authors have found the Chilean water market and governance system to have created challenges surrounding lack of data and information on the market and challenges in holding water users to account due to lack of enforcement capacity and informality of the governance approach. Significant barriers also exist in integrating environmental and social considerations into the water governance framework (Hill 2012b, p. 153). NGOs have been weakened because of the predominance of private property (Hill 2012b, p. 202). Further, the predominance of the private property in water has been at the expense of communities and a communal human right to water with very serious impacts on equity (Hurlbert and Diaz 2012), both an institutional design principle of adaptive governance (Huntjens et al. 2012) and a determinant of adaptive capacity (IPCC 2001).

Regarding water as public property owned by the people (via the state, or Crown in the case of Canada) allows for a legislative framework to be established governing the relationships surrounding water. In this sense, water is not left as a true "public property" equally and freely accessible by all. The wealth of literature surrounding water laws and governance systems accounts for the detailed and technical rules governing water's access and use when still owned by the state for the public (Bakker 2007). The public property system can have significant impediments in relation to adaptation including inefficient allocation of water interests and inability to monitor and claw back unused water allocations (Percy 2004). However, it is possible that the government can balance goals on environmental resilience, development, and community rights to water by retaining the overarching ownership of water. Legislative schemes generally provide for minimum flows being retained in river systems to protect the environment, priorities in times of shortages for community drinking water, and conditions on licenses to ensure against over-allocation and changes in the water resource (Hurlbert 2009b).

Some of the most significant impediments to the adaptiveness of public property water regimes as described above relate to the increasing neoliberal agenda of reduced government (in both size and spending) (Hurlbert and Diaz 2012) as well as the difficulty of the government in balancing all of the necessary components in good adaptive water governance. First, there are well-documented difficulties in the policy interface of government with science and specifically climate change science (Choi et al. 2005; Hoppe 1999); second, there are difficulties in incorporating local knowledge into policy (Gagnon and Berteaux 2009). Without the incorporation of local knowledge, people and communities regard the rules surrounding water as imposed by a distant government and may even not be aware of the rules in order to solve conflict (Hurlbert 2009a). Thus a public property interest in water has potential to allow for an adaptive law goal of allowing for multiple forms of resilience through a polycentric structure embracing iterative consultative public input. However, much is dependent on government and the framework of laws structuring the access to water and processes governing these.

The common property interest of water holds much promise of facilitating adaptive law goals (in that all users determine the balancing of environment and development needs in relation to water). It differs from the public property interest in that government does not have the power to determine what is in the public interest; this power is determined by the users. Of course potentially nonusers (future generations or entities such as flora and fauna without legal standing) are sidelined. The common property interest also embodies the "structure" of adaptive law because of participating at multilevels in decisions (local community, provincial, and national) and utilizes "methods" allowing for discretion which respond to change and "processes" that are iterative and continuous. Increasingly examples of successful comanagement of resources are being reported (Armitage et al. 2007), but these of course entail a sharing of power between the government and users; examples of a pure common property management are elusive. In addition, comanagement has barriers to adaptation including not achieving poverty reduction, reinforcing local elite power, and exclusion of marginal stakeholders from decision processes (Berkes 2009).

Conclusion

This chapter focuses on assessment of laws and legal mechanisms, specifically a property interest in water, to improve adaptive capacity of rural agricultural producers to respond to climate variability and change, and specifically drought, in the future. Certainty of law is an important attribute in a democratic society; however, often certainty is synonymous with inflexible, traditional laws, perhaps no longer appropriate in times of rapid social, geographical, and natural system change. Law is one institution that operates within a wider governance context and contributes to the adaptive capacity of a community. Appropriate provisions are required in both public and private law in order to ensure that the institution of law can adapt to future variability and extreme climate events of drought and flood. Principles of adaptive governance (responsiveness, flexibility, etc.) and adaptive law (polycentric responses to conflict with iterative feedback loops) are appropriate.

By comparing the three property interests in water, public, common, and private, an assessment is made of how this legal instrument can facilitate or hinder adaptive capacity. Common property interests in water are most reflective of adaptive law principles. However, significant barriers and difficulties exist in finding a case where water governance is conducted in a common property manner. One example is in an irrigation district context. More research is required in relation to the context and scale in which water could be ascribed with a common property interest.

Private property instrument of water can in certain contexts and applications add features of resiliency. Alberta has had positive experiences with allowing the transfer of a water interest in certain prescribed limited situations. However, the complete adoption in Chile of a market interest in water, or the employment of a private property instrument, has had negative impacts on adaptive capacity. The water market has been plagued by shortages of information, reduced social capital, and disparities in access to water with equity issues (Hurlbert and Diaz 2012).

Public property (if it is accepted that government-administered schemes reflect this) could envision adaptive law and governance principles if orchestrated appropriately. A pejorative review of legislation and policy might be conclusive of the virtues of this ascribed property tool in relation to water representing adaptive governance and law. However, without delving deeper into an institutional analysis of how law actually operates within a socio-environmental system, such a desktop review may be misleading. Further research is required to delve deeper into the lived experience of those with water interests in relation to different public property, or government-administered schemes are required.

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Climate Change Adaptation: An Overview on Challenges and Risks in Cities, Regions Affected, Costs and Benefits of Adaptation, and Finance Mechanisms

Manal El-Batran and Mohsen Aboulnaga

Contents

Abstract

Adaptation of climate change (CC) has been defined by many of the world's leading institutions such as IPCC and UNFCCC in various contexts. Many studies, research, and reports on CC mitigation were reported, but less was done on adaptation. Adaptation is strategically needed to lower the impact of CC that is manifesting coupled with serious challenges and risks for cities such as high temperatures, water

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availability, floods and droughts, and sea-level rise damage to coastal areas. Adaptation is vital to offset CC impacts on environment challenges such as soils, biodiversity, inland water, and marine environment. By adopting effective measures and early actions for CCA, money and lives can be saved. The EU Climate Action highlighted six areas where adaptation measures should be applied and financed. Strategies for CCA are vital at all levels of government administration whether local, regional, or national to counterbalance CC. Areas with high vulnerability to CC impact and need adaptation actions, policies, and measures; are mainly in Europe, the Mediterranean, Asia-Pacific, North America, and Africa; and have been highlighted. Gaps in the assessment of the full costs of CC compared to that of CC mitigation were discussed. Many researches that have been conducted on CC policy are mainly for mitigation, but less was focusing on the assessment of cost. The EU which allocated 20 % of funding to climate, costs, and benefits of adaptation is recently focusing on the cost inclusion of adaptation in urban policies and projects and the cost of actual adaptation measures. Costs and benefits of adaptation options were reviewed by UNFCCC, mainly methodological issues for estimating the costs and benefits of adaptation options followed by the economics of adaptation in light of the review. Information and guidance for the costing of adaptation options are outlined, including many major methods and techniques for adaptation option appraisal and decision analysis in the climate change adaptation that have been recently reported such as cost-effectiveness analysis (CEA), the cost–benefit analysis (CBA), and the multi-criteria analysis (MCA). It also presents a comparison between these costing and benefits and techniques. This chapter reviews and discusses five main folds: (1) why is climate change adaptation necessary; (2) the importance of climate change adaptation (CCA); (3) what are the methods of CCA; (4) the widening gap between CC impacts and required adaptation measures, including the most affected regions and case studies of CCA in Africa, Asia, Europe, and Latin America; and (5) what is the cost of CCA including how costs of CCA are assessed and financed. It also attempts to review the CCA funding mechanisms with focus on cities and urban areas. It is clear that many actions, measures, and funds have been developed, but the gap is still widening in developing poor countries, and the robust machinery to significantly execute the current funding in productive channels is highly required if facilitating adaptation to CC impacts and minimizes risks.

Keywords

Climate change • Adaptation methods • Adaptation actions and measures • Risk in cities • Cost and benefits • Adaptation and finance mechanism • Vulnerable countries

Introduction

Climate change impact has been widely manifested worldwide in the last 10 years. Climate change (CC) means "global warming" or the "greenhouse effect." This is caused by the emissions of greenhouse gases (GHGs) into the atmosphere through enormous human activities, particularly the burning of fossil fuels. In this part, the challenge of CC, from a development perspective in terms of how can developing countries anticipate and respond to the threats and opportunities brought by CC, is considered.

It is widely recognized that the climate is changing. While local, regional, central, and federal governments continue their efforts to reduce GHG emissions, it is important to prepare for CC impacts that are already underway. This includes more extreme heat and flooding, as well as increased damage to energy, water, and transportation infrastructure from extreme weather events. Also, economic development in many countries remains fundamentally based on fossil fuels. This means societies are going to experience some degree of CC and will have to implement a combination of reactive and anticipatory measures to adapt. There is still much uncertainty about how the climate is likely to change at both regional and national levels. Policy makers and planners often require information about CC at scales which have high levels of uncertainty. Responses to extreme weather and anticipatory planning for CC therefore need to be flexible and resilient to a much wider range of climate conditions than are currently experienced. They must also pursue this on the basis of limited knowledge. For various reasons, more attention in CC research and policy has been given to mitigation than adaptation. Uncertainty about the details of CC whether rainfall will increase or decrease and the timescales over which CC will occur are likely to influence decision-making about funding priorities and target activities. There is, however, close agreement between development agendas and the effects of CC in areas with high climate variability and extremes of weather. It is in these situations that CC will most directly affect vulnerable people, such as those living in small-island states or low-lying coastal areas, subsistence farmers, flood-prone communities, and urban dwellers exposed to extreme temperatures and potential increases in disease transmission. Development work can provide valuable insights into the context-specific and socially mediated links between vulnerability and extremes of weather. Cause and effect between hazard and disaster occurs through human agency, and it is here that development research has much to offer our understanding of climate–society interactions.

This chapter reviews and discusses five main folds: (1) why is climate change adaptation necessary; (2) importance of climate change adaptation (CCA); (3) what are the methods of CCA; (4) widening gap between CC impacts and required adaptation measures, including the most affected regions and case studies of CCA in Africa, Asia, Europe, and Latin America; and (5) what is the cost of CCA including how costs of CCA are assessed and financed. It also attempts to review the CCA funding mechanisms with focus on cities and urban areas.

Why is Climate Change Adaptation Necessary?

Climate change adaptation (CCA) has been defined by many of the world's leading institutions in various contexts. These briefly describe adaptation as action taken, adjustments to a process, strategies, or outcomes. In a different setting, CCA consists of initiatives and measures to reduce the vulnerability of natural and human systems to actual or expected climate change effects. They can be spontaneous or planned responses to actual or expected conditions (Regmi et al. 2010). Adaptation is strategically needed to lower the effect of CC that is happening and poses serious challenges and risks for cities such as high temperatures (heat waves and storms), water availability, floods and droughts, and sea-level rise damage to coastal areas. Sectors that are affected encompass infrastructure and buildings, energy demand and supply for cooling and heating, agriculture production in terms of crop yields, tourism, insurance, and crosscutting business. Also, adaptation is important to offset CC impacts on environment challenges such as soils, biodiversity, inland water, and marine environment. Additionally, social dimension of CC has been manifested by health impact, population employment, and education; hence, adaptation measures are vital to reduce such impacts. By adopting effective measures and early adaptive actions for CCA, money and lives can be saved. Tompkins and Adger (2003) explain the differences between mitigation and adaptation, noting that they share the same underlying factors and are not substitutes for each other but are essentially complementary. They argued that it may be difficult to generalize about how adaptation occurs and how strategies can be exploited. Adaptation may be in response to or in anticipation of events and implemented through the actions of individuals, governments, or other groups.

CCA has been defined by many of the world's leading institutions in various contexts (Gagnon-Lebrun and Agrawala 2007; Harley et al. 2008; UNFCCC 2010a; Brooks et al. 2011; Preston et al. 2011; Poutiainen et al. 2013; Bours et al. 2014). Adaptation refers to the ability of human and ecological systems to manage or cope with a changing climate. Adapting to these impacts must take place at all levels of the government. However, as most impacts will be felt at the local level, municipalities/governorates in particular need to respond to these local challenges. Major challenges also surround the equity issues of CC, particularly between developed and developing countries, in terms of historically unequal emissions of GHGs, constraints on future emissions, and unequal exposure and capacity to adapt to the effects of CC. These are questions to which the developing world and the development community can bring considerable insights (id21 Insights 2004).

International negotiations in Bali, Indonesia (December 2007), failed to achieve consensus on targets for climate change mitigation (CCM), i.e., reducing GHGs' emissions. However, countries have agreed to negotiate mitigation targets for after 2012 by the end of 2009, when the countries meet again in Copenhagen (id21 Insights 2008b). A vital point that had been stressed by the Copenhagen Conference Declaration (CopCD) remains a source of major differences between developed and developing countries: the principle of "common but differentiated" responsibilities. Developing countries insist that developed ones have a historical responsibility and should cut emissions and provide developing countries with finance and technology to do their part. On the other hand, they ask about the growing contribution of developing nations to global warming (Tolba 2011).

If we are to save our planet there must be a real willingness to cooperate, with developing countries accepting part of the responsibility for current and future emissions and developed countries bearing the full responsibility for past emissions. This cannot be achieved without open discussions between both sides. Developing countries must realize that the total 2009 CO_2 emissions by China surpassed those of the USA, the biggest emitter, and that emissions by India are similar to those of Japan or Russia. This indicates that we must immediately begin a series of nonstop informal consultations between the leading countries in both camps with a view to achieving compromises before UNFCCC COP20, 2014. The UN must play the role of a global body concerned about serious global problems. It should also offer a neutral forum but work to produce meaningful compromise formulations that bring together opposing views. Too much is at stake to allow such useless negotiations to continue forever.

The outcomes of the United Nations Climate Change Conference in Cancun, Mexico, December 2010, proved once again that governments are not serious enough about the issue. Nonstop consultations between developed and developing countries must now take place, and they should achieve tangible and effective compromises before the forthcoming UNFCCC COP20 in Lima, Peru, due on December 2014. Efforts are needed to develop more scientific evidence, it is true, but we certainly know enough (Tolba 2011). However, CC has shot to the top of the world agenda in the last 10 years. The first push came from Albert Gore’s 2006 famous film “Inconvenient Truth.” It showed in a dramatic way the ice melting in the North Pole as well as the very strong storms, hurricanes, and floods that swept through various areas of the globe. The second push came, again in the year 2006, from the Chief Economist of the World Bank, Sir Nicholas Stern’s report. When he retired at his home country, Tony Blair, former Prime Minister of the UK, requested him to convene a group of experts to prepare a report on the economics of CC. The British expert group had detailed discussions with experts from all over the globe. The Stern report made three telling points:

(a) Actions today to mitigate climate change cost 1 % the global gross domestic product (GPD) while facing its impacts later will cost the world 5 % of its total GPD.
(b) Any spending in the next 20 years on actions to mitigate climate change will have impact only after 2050 because of the GHGs’ life spans.
(c) Increase of the average global temperature will continue for the next 20 years even if emissions are stopped today, again because of the GHGs’ life spans.

The UN Intergovernmental Panel on Climate Change (IPCC) issued its Fourth Assessment Report in November 2007. In the same year, the IPCC received the Nobel Prize jointly with Al Gore in recognition of their effort to bring the seriousness of the issue of CC to the attention of the world community. The first sentence in the IPCC Synthesis Report of 2007 stated that “Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.” They were so categorized far beyond the normal language used by the scientists. The IPCC report further stated that “Most of the observed increase in global average temperatures since the mid of the twentieth century is very likely due to the observed increase in anthropogenic GHG concentrations."

Climate change in Africa is manifested in many forms whether in terms of water, agriculture, aridity, energy demands, or security. The IPCC Report of 2007 also gave the following three disturbing facts about Africa:

(a) "By 2020, between 75 and 250 million people in Africa are projected to be exposed to increased water stress due to climate change."
(b) "By 2020, in some African countries, including North Africa, yields from rain-fed agriculture could be reduced by up to 50 %. By the same date agriculture production, in many African countries is projected to be severely compromised. This would further exacerbate malnutrition."
(c) "An increase of 5–8 % of arid and semi-arid land in Africa is projected by 2080 under a range of climate scenarios."

The IPCC based its emphatic conclusions on global warming on a number of facts which it presented in its 2007 report:

(a) CO_2 atmospheric concentration increased from 280 PPM in 1750–379 in 2005. The average concentration for the last 365,000 years was 300 PPM.
(b) Eleven out of the 12 years (1994–2005) were the hottest years on record.
In the last 50 years, the number of cold days and nights, hot days and nights, and heat waves increased.
(c) Average sea-level rise was 3.1 mm/year between 1993 and 2003, compared to an average of 1.8 mm/year during the period of 1961–2003.
(d) There is up to 97 % confidence within the IPCC that the average global temperature will increase by 2 °C by 2050. This could happen in the year 2035.
(e) The IPCC had more than 50 % confidence that the average global temperature will increase in the next century by 5–6 °C – a situation unfaced before by human beings.

All these disturbing facts were further stressed and accentuated by the UNEP 2007 State of the Environment Report (SOE) and UNDP 2007 Human Development Report; both were devoted entirely to the issue of CC. Additionally, several reports by the World Bank, the European Union (EU), the Organisation for Economic Co-operation for Development (OECD), the US National Science Foundation (NSF), and several others were published in 2008 and 2009 stressing the global negative impacts of CC. The same old very general statements that were adopted in tens of earlier conferences starting from the First International Conference on Climate Change convened in 1988 in Geneva by WMO and UNEP in cooperation with UNESCO, WHO, and FAO. Nevertheless, none of them went beyond stating intentions with no specific details of how and during which period any of these statements will be implemented.

One of the points stressed by the Copenhagen deceleration was that of the principle of common but differentiated responsibilities. This point has been and still a source of huge differences between developed and developing countries. Developing countries insist that developed ones have historical responsibility and should cut emissions and provide developing countries with finances and technology. Developed countries ask and rightly so, what about the current and the future. If we want to move ahead to save our planet, there must be a real willingness to cooperate by the two groups, developing countries accepting part of the responsibility for current and future emissions and developed countries take full responsibility for past emissions. This cannot be achieved without direct and open discussions between the two sides, talking to one another rather than past one another. Developing countries must realize that the total CO_2 emissions by China in 2009 surpassed that of the biggest emitter, the USA, and that emissions by India are similar to those by Japan or Russia.

These disturbing facts were further stressed and accentuated by the United Nations Environmental Programme's State of the Environment Report (SOE), the United Nations Development Programme's Human Development Report and other reports by the World Bank, the European Union (EU), the Organisation for Economic Co-operation for Development (OECD), the US National Science Foundation (NSF), and others. Yet, the outcome of the United Nations Climate Change Conferences at Copenhagen (2009), UNFCCC (2010b, 2011) proved that governments are not serious enough about the issue. If human beings want to survive, nonstop consultations between developed and developing countries must now take place, and they should achieve tangible and effective compromises before the next climate change conference at the end of 2014.

As pointed out by Tolba (2011), "Governments have no option but to halt the dialogue of the deaf and agree on four basic points if Durban is to be a success. These are: agreement on the verification of emission reductions; agreement between developed and developing countries on the principle of common but differentiated responsibilities; specific targets for the GHGs' emissions in developed and developing countries; and finally, developing countries need to be offered a grace period before applying the reductions required by a new treaty. Advanced developing countries (China, India, Brazil, South Korea, Malaysia, etc.) may have a shorter grace period than other developing countries - certainly shorter than those for least developed countries and small-island states. As per the Copenhagen agreements, parties need to define specific figures for financing a climate change adaptation fund, and to establish the details of the technology transfer mechanism. The most affected countries should be supported urgently."

Importance of Climate Change Adaptation

The impacts of climate change are already being observed around the world, from retreating glaciers to changing seasons and rainfall patterns. Climate change (CC) is likely to be evident in the future through more frequent storms, droughts, heat waves, floods, and other extreme events. Amid ineffective local governments that provide inadequate infrastructure and services required to reduce climate change-related risks and vulnerabilities, most of the world's urban populations are living in cities or smaller urban centers that are ill equipped for adaptation. Infrastructure and buildings are considered a key part of adaptation concerns, but much of the urban population in Africa, Asia, and Latin America has no infrastructure to adapt – no all-weather roads and piped water supplies or drains – and lives in poor-quality housing in floodplains or on slopes at risk of landslides (Satterthwaite et al. 2007).

According to El-BATRAN (2010), climate change extreme events, particularly floods and droughts, have severe implications on various sectors and services, including water, energy, livelihoods, transport, and health. In spite of the very low contribution of Egypt in the global GHG's emissions, Egypt is considered as one of five highly vulnerable countries to climate change impacts. The January 2010 floods in North Sinai left 780 homes totally destroyed, 1,076 submerged, and much other damaged. At least 3,500 persons have been affected by the floods or are homeless. The floods were of a surprise as North Sinai had not seen such floods in 30 years as shown in Figs. 1–3. Also in December 2013, the cold spell and heavy snow falls (never happened since 112 years) that totally covered most of Cairo outskirts (Altagamoah, New Cairo) are other manifestations of climate change impact as exhibited in Fig. 4. Also in May 2014, Egypt's eastern part (Taba and Sinai) and Upper Egypt (Aswan) were stormed by torrential rain that had led to floods (Figs. 5 and 6). So, adaptation to climate change is worse in the secondary cities than in capital cities, particularly in case of Figs. 1–6.

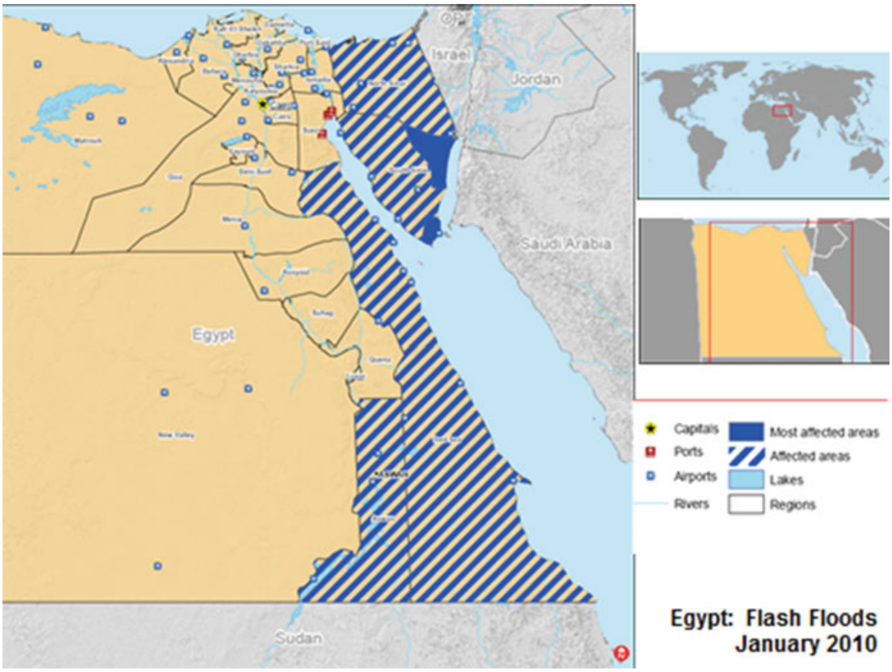


Fig. 1 Egypt's flash flood, January 2010 (Source: Egyptian Red Crescent)

Fig. 2 Settlements built in the path of old stream torrents, Egypt – vulnerable area (Source: El-Batran 2010 – Image Credit: authors)

Fig. 3 Increased vulnerability of slum areas to flood damage, wind, and fires in rural Egypt (Source: El-Batran 2010 – Image Credit: Authors)

Fig. 4 Snow and cold spells, Al Tagamoa, New Cairo, Egypt – December 2013 (Image Credit: http://urbanmediadaily.com/cairo-gets-first-snowfall-100-years/)

Fig. 5 Torrential rain and floods Taba and Sinai, eastern Egypt – May 2014 (Image Credit: http://www.google.com)

Fig. 6 Torrential rain and floods in Red Sea area and Upper Egypt – May 2014 (Image Credit: http://www.google.com)

Each of these extreme events may affect the security and sustainability of development throughout the world. Developing countries, particularly least developed countries, are likely to be exposed to the greatest impacts. However, CC is caused by current and past emissions from industrialized countries that have more resources to cope with the impacts (id21 insights 2004). Climate-related risks come not only from direct exposure to natural hazards such as floods or droughts but also from the vulnerability of social and economic systems to the effects of these hazards. Responses to these risks should combine two approaches: (a) short-term measures to react to hazards when they occur and (b) structural reforms that enhance the capacities of communities to adapt. Climate change adaptation (CCA) is an adjustment in natural or human systems, which occurs in response to actual or expected climatic changes or their effects (id21 Insights 2008b).

Adapting to CC means adjust and acclimatize to risks from observed or expected changes. Governments, enterprises, and households will all have to adapt. In most urban centers, community organizations and local nongovernmental organizations are also important, especially where they are influential in building homes and communities and providing services within informal or illegal settlements (Satterthwaite et al. 2007).

In human systems, adaptation can reduce harm or exploit opportunities. The disaster risk reduction (DRR) is the development and application of policies and practices that minimize risks to vulnerabilities and disasters. The DRR is an essential part of adaptation – it is the first line of defense against climate change impacts, such as increased flooding or regular droughts. The DRR is now lending its expertise and humanitarian experience to climate change adaptation programs (id21 Insights 2008b).

Mitigation and adaptation are the two responses to CC. Mitigation means reducing emissions of greenhouse gases, the main cause of human-induced climate change, whereas adaptation means adjusting to any new climatic conditions caused by natural and human-induced change. Many parts of the world have had to cope with previous climate variability and have developed strategies to do so. Adaptation can be undertaken in anticipation of impacts or after these have occurred. These can be initiated by individuals through market exchanges and social interactions or through coordinated measures by government or other groups. The mix of anticipatory or reactive adaptation action actually introduced will depend on the existing vulnerabilities of each community or individual, as well as institutional processes, regulatory frameworks, property rights, access to resources, and social conditions. Adaptation is place specific and context specific: there is no single plan for how adaptation should occur.

However, lessons learned from responding to past hazards may be useful for planning for future CC. Investments in adaptation and mitigation are necessary, but these are not substitutes for each other. In fact, the ability of societies to reduce their emissions and to adapt is determined and constrained by the same underlying factors. The resilience of institutions and of resources sensitive to changes in the climate is central to meeting the challenge. These issues are often magnified in developing countries, which are coping with economic globalization and other challenges simultaneously (id21 Insights 2004).

Adaptation is a risk-reduction strategy for ameliorating the adverse effects of CC on human and ecological communities and for capitalizing upon potential opportunities. Adaptation specifically refers to actions, policies, and measures that increase the coping capacity and resilience of systems to climate variability and CC (CSIRO 2006). Also, adaptation can be generally divided into two types of measures: vulnerability reduction and resilience enhancement (Kay and Hay 1993). The term "vulnerability" is used to describe the attributes of a system which will react adversely to the occurrence of external or internal stresses (Nitivattananon et al. 2009). The EU Climate Action highlighted six areas where adaptation measures should be applied and financed as illustrated in Fig. 7 (EEA 2012). The first two measures are highly needed for Africa and mainly Egypt since water and energy shortages are high on the government agenda.

Strategies for CCA are vital at all levels of government administration whether local, regional, or national to counterbalance CC. In addition to other adaptation measures, sustainable urban design, resilient urban management, and improving infrastructure to be green would contribute toward lessening these effects. Given the limitations of impact-driven coastal vulnerability assessments in considering

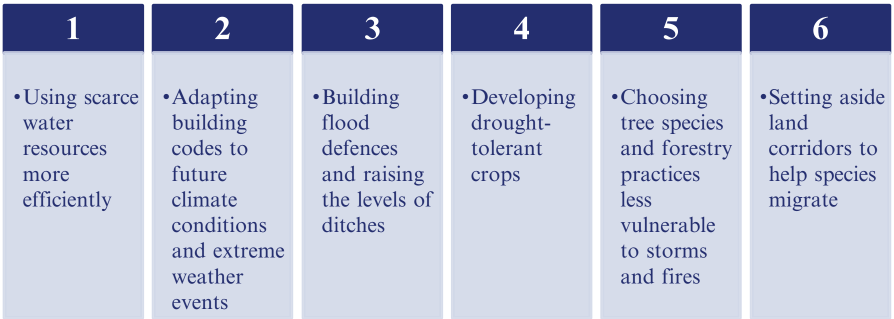


Fig. 7 Adaptation measures (Source: EU Climate Action)

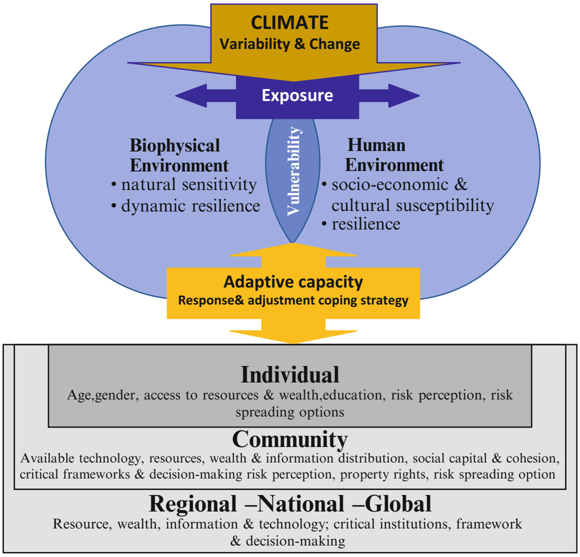


Fig. 8 Integrated vulnerability framework (Source: Modified by Dolan and Walker 2004)

both physical and social aspects of vulnerability and in light of the present need for community-based approaches to adapting to climate change-related risks, Dolan and Walker (2004) proposed an "integrated" framework (Fig. 8).

Such approach considers inherent susceptibilities and resiliencies of both biophysical and social environments as an interrelated and interdependent human environment system. Vulnerability, in this context, can be defined as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (Watson 2001).

Vulnerability to CC is considered to be high in the South due to social, economic, and environmental conditions that amplify susceptibility to negative impacts and contribute to low capacity to cope with and adapt to climate hazards.

Moreover, projected impacts of climate change generally are more adverse for lower latitudes, where most countries in the South are located, than for higher latitudes. Because of the high level of vulnerability, there is an urgent need in the South to understand the threats from climate change, formulate policies that will lessen the risks, and take action (Abou-Hadid 2006). The danger is greatest, where natural systems are severely degraded and human systems are failing and therefore incapable of effective response, specifically in deprived nations.

Furthermore, land degradation and desertification may also be exacerbated in these areas, posing additional threats to human well-being and development, added by intensified human pressures on lands and poor management (Elsharkawy et al. 2009). The agriculture and food resources including livestock and fisheries of the rural poor are threatened by CC with all its impacts, and the vulnerability to adverse health impacts is greater where health-care systems are weak and programs for disease surveillance and prevention are lacking. In addition to multiple factors converging to make the people inhabiting coastal zones and small islands highly endangered from the causes of SLR (Leary and Kulkarni 2007). The coastal Zone and small islands are, therefore, particularly vulnerable to the impact of SLR in addition to impacts on water resources, agricultural productivity and human settlements. But, if no protection action is taken, the agricultural sector will be the most severely impacted, followed by the industrial sector and the tourism sector by a SLR.

The term "resilience" is used in the opposite sense to vulnerability – resilient attributes of a system will typically reduce the impact of internal and external stresses. According to Dolan and Walker (2004), adaptive capacity is reflective of resiliency, such that a resilient system has the capacity to prepare for, avoid, moderate, and recover from climate-related risks and/or change. Nonetheless, Satterthwaite (2008) stated that successful adaptation is about the quality of local knowledge, local capacity, and willingness to act. City governments should have key roles, not only in changing what they do business, but also in the adaptation they encourage and support (Fig. 9).

Development should increase people's ability to act to reduce their vulnerability to climate change – due to improved local knowledge and increased income – and increase poorer groups' ability to influence local governments' action. Insurance can spread risks and reduce the financial hardships linked to extreme events. It can also provide incentives for adaptation and risk reduction, but only a very small proportion of urban households and enterprises have insurance. For low-income groups, supporting the measures they already employ to reduce risk and vulnerability has more relevance – for instance, through community-managed savings groups.

In many countries, groups formed by people in "slums" or informal settlements engage in risk management and risk-reduction initiatives. These include upgrading slums and squatter settlements, developing new housing, and improving water supply, sanitation, and drainage. In some cities, such groups have also developed detailed maps of informal settlements and collected data on who lives there to guide new infrastructure. In Durban, South Africa, adaptation plans demonstrate the important role that local governments can and should play. Adaptation to CC has

1. • Ensuring the availability of an appropriate and widely understood information base about climate change and its local impacts –this does not exist in most cities
2. • Land-use planning that avoids high-risk areas and shifts activities away from them, including ensuring that low-income groups can find affordable land for housing on safe sites.
3. • Revising building and infrastructure standards, in ways that do not impose unaffordable costs.
4. • Planning and public sector investment that considers climate change. For example, much infrastructure needs to be designed to cope with likely changes over 50 to 100 years.

Fig. 9 City government key roles (Source: Satterthwaite (2008))

to be built into the core of all urban planning and management. It is, however, difficult to get local governments to act on adaptation. There are always other priorities that seem more pressing and, at present, the information base on the likely local impacts of CC is weak.

In most cities, planning for adaptation must first overcome an inadequate infrastructure base.

Estimates of adaptation costs have yet to recognize this. Adaptation will need to address this deficit as well as making building improvements, strengthening of lifeline infrastructure, and hazard modification (for instance, repairing and strengthening flood, storm surge, and coastal defenses). All cities need effective disaster risk management plans, both to reduce risks and have in place appropriate responses. Good disaster preparedness is a key part of adaptation. However, adaptation means "better coping," rather than removing risks. It does not remove or even reduce the urgency for mitigation: even for relatively low amounts of warming, there are natural and technical constraints to adaptation. Without strong and early mitigation, the difficulty and costs of adaptation will grow rapidly. While good development and adaptation to CC risks are complementary in important ways, most adaptation does entail opportunity costs (Satterthwaite 2008).

Methods of CCA Assessments and Measures

Many methodologies have been set and used for CCA. These were derived and established by the World Bank, UNEP, and Mainstreaming Adaptation to CC in Agriculture and Natural Resources Management projects. Guidance notes for lessons learned, best practices, recommendations, and useful resources for integrating climate risk management and adaptation to CC in development projects program planners. As highlighted in the "Financing the Resilient City" report

(ICLEI 2011), it provides a bottom-up strategy for building capacity to finance and implement resilience for development. This strategy is centered on the idea of establishing local capacity to plan, finance, execute resilient improvement, and note to raise funds (ICLEI 2011). There is always a challenge in matching the precise enabling finance with local demand for urban resilience. This highlights the importance of the right approach. A number of approaches have been developed to address the issue of mobilizing financial resources.

Widening Gap Between Climate Change Impacts and Required Adaptation Measures

Despite the fact that CC impacts are manifested in many countries, particularly the poor ones, CC adaptation and enacted measures are not yet showing enough to eliminate such risks. This can be seen due to the unavailability of funds to address these impacts; besides, the current local authorities and government are not the institutes for such an adaptation, and they lack the capacity to build and invest, and current urban policies are not addressing CCA.

Climate Change Most Affected Regions

Climate change adaptation (CCA) is bound by population, economic sectors, and social constraints. Areas that are highly vulnerable to climate change (CC) impacts and need adaptation actions, policies, and measures are mainly in Europe, Mediterranean, Asia-Pacific, North America, and Africa. Migration is a key issue of demography that causes stress on the national infrastructure when it comes to climate change impacts (Sheribinin 2013). The diverse linkages between climate change and security, including risks of conflict, national security concerns, critical national infrastructure, geopolitical rivalries, and threats to human security, have been recently highlighted and reviewed by Gemenne et al. (2014). In this study, it has been concluded that much analysis overemphasizes deterministic mechanisms between climate change and security. The importance of mapping these impacts, whether major or minor, is vital in understanding the severity, sectors, and areas. In a study by Sheribinin (2013), regions that are anticipated, based on combinations of high exposure, high sensitivity, and low adaptive capacity, to suffer significant impacts from CC have been highlighted. In the past 5 years, “hotspots” mapping on CC has helped in identifying spots that are affected by the phenomena and that will be impacted in the future. Hotspots mapping efforts underlined a range of issues and sectors such as vulnerable population, humanitarian crisis, conflict, agriculture and food security, and water resources. Many developed climate change “hotspots” have been established by researchers, advocacy groups, and NGOs (Sheribinin 2013).

In Africa, “hotspots” mapping has helped in communicating areas that CC has impacts on and may require adaptation. These areas are (a) Al Wahda Dam, Morocco; (b) Cape Floral Region, South Africa; (c) Etosha National Park, Namibia; (d) Lake Tanganyika, Tanzania; (e) Salonga National Park, D.R. of Congo; (f) Western Highveld, South Africa; and (g) Yirgacheffe, Ethiopia (Union of Concerned Scientists 2011). The top impact and other impacts in these six countries are mainly freshwater (extreme dry), people (water use, food, and coasts), temperature (air and water), and ecosystems (land, lakes, and rivers). Other regions in Asia, Australasia (Australia and New Zealand), Europe, Latin America, North America, polar regions, and small islands can be found in the same reference. This tool (hotspots mapping) can be of significance in identifying the direct and appropriate measures, actions needed, and cost allocation due to these impacts and the required funds and financial mechanism for cities to counterbalance climate change.

Many affected countries will be further impacted by CC across the world based on geographical location and population. Studies carried out by international organizations (UNFCCC and EC) stated that 10 places worldwide that are the highly vulnerable, in addition to Bangladesh, Serbia, Australia, Myanmar, and Sudan, are Uganda, the Alps, Northwest Passage (Arctic), Washington, D.C., Gulf Coast (Florida), Island Nations, the Great Barrier Reef, Northern Europe, Italy, and Nepal (Abou-Hadid 2006). In South Asia, CC is predicted to have drastic consequences, particularly in agriculture, which employs more than 60 % of the region's labor force (Oxfam 2010). Predicted impacts of CC include increased variability in both monsoon and winter rainfall patterns; increase in average temperatures, with warmer winters; increased salinity in coastal areas as a result of rising seas and reduced discharge of major rivers; weakening ecosystems; the recession of glaciers in the Himalayas; and increased frequency and/or severity of extreme weather events (floods, cyclones, and droughts).

Moreover, the recent IPCC report on climate change stated that Egypt is one of the nations that will be heavily affected by the impact of climate change phenomenon. The World Bank study (Dasgupta et al. 2007) stated that Vietnam is among the countries most heavily affected by the consequences of climate change: of the 84 coastal-developing countries investigated in terms of sea-level rise (SLR), Vietnam ranked first in terms of impact on population, GDP, urban extent, and wetland areas and ranked second in terms of impact on land area (behind the Bahamas) and agriculture (behind Egypt). Hence, it requires intermediate planning for adaptation (Waibel 2009). Like Egypt, almost 11 % of Vietnam's population, mostly those people living in the two river deltas, would be impacted by an SLR of just 1 m (Dasgupta et al. 2007).

The Stern Review on the Economics of Climate Change confirms Vietnam's high vulnerability to climate change. Vietnam is ranked fourth behind China, India, and Bangladesh in terms of the absolute number of people living in vulnerable, low-elevation coastal zones (LECZ). This is considered the highest percentage of all countries worldwide (Waibel 2009). It has been concluded that "vulnerable settlements in low-income countries clearly deserve international support to adapt to climate change."

Climate Change Adaptation (CCA): Case Studies

Many countries have taken steps toward climate change adaptation such as Finland, Sweden, Norway, Scotland, and Greenland. The CCA themes were centered on sustainable energy, transport, tourism, and risk management. In these cases, a number of real adaptation activities were carried out by several different communities. These cases were part of the Clim-ATIC project that attempted to identify and understand the issues relevant to stakeholders at a local level in terms of actual development and implementation (Climate Change Adaptation Resources 2014).

This project undertook a number of key activities over a 3-year period, with communities and community sector stakeholders across five regions of the Northern Periphery, to build the necessary knowledge on (a) investigation, collation, and communication of relevant information on potential direct and indirect impacts of climate change to small peripheral rural communities; (b) development of adaptation strategies by these communities to avoid or reduce the negative impacts of climate change, while taking advantage of opportunities; (c) implementation of adaptation demonstration projects with a focus on transnational activities; and (d) establishment of a formal mechanism to disseminate knowledge for community adaptation. Table 1 shows these case studies and related themes.

Nevertheless, when compared with those in poorer countries, little can be noticed; however, cases were reported in the following section about Africa, Asia, Latin America, and Europe.

Africa's Pioneering Countries in Climate Change Adaptation

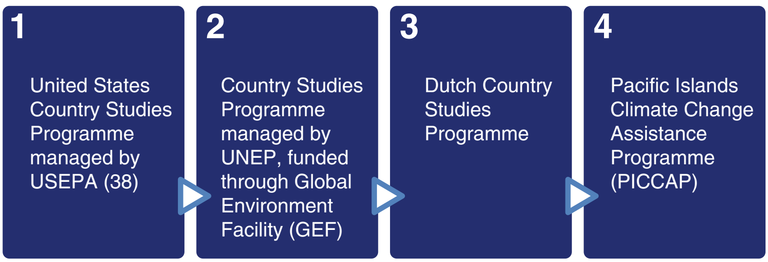
According to the ICLEI report on their members in Africa which exhibited true commitments on climate change adaptation (CCA) through the C40 group, two key countries have led by tremendous efforts in terms of CCA. These are Cape Town, South Africa, and Dar es Salaam, Tanzania. These cities were involved in the pioneering CCA in Africa program and are pioneering on sustainability and manifesting great leadership through participatory research actions over many years as part of the over 1,000 strong international ICLEI network of local governments and cities. For Cape Town, it is also a leading and founding city of the local action for biodiversity (LAB) program and has been engaged in various aspects of sustainability through the ICLEI network, including advocacy work linked to the UN-CBD, whereas Dar es Salaam participated in a Food–Water–Energy Urban Nexus project that is implemented by ICLEI Africa and funded by GIZ (ICLEI 2014).

Nevertheless, in poor communities, CCA was noticed. In Accra (Ghana), Kampala (Uganda), Lagos (Nigeria), Maputo (Mozambique), and Nairobi (Kenya), a discussion with the residents of poor communities in cities was conducted through a program called ActionAid, including many points of concern (Box 1). Flooding had become more frequent in each of these cities; thus residents suggested that it had become less predictable. Residents emphasized that the lack of adequate drainage and poor management of existing drainage, unplanned and unregulated urban development as well as the lack of attention to the problem by the government, and changes in weather patterns are the main reason for flooding.

Table 1 Developed countries case studies – Clim-ATIC project (2008–2011)

Country	Case studies	Themes
Greenland	Adaptation strategies – Ilulissat Icefjord	Sustainable Energy Transport Tourism Risk Management
	Adapting sledge and snowmobile tracks in Sisimiut	
	Climate change vulnerability – Greenland	
	Biogas	
	Breaking ice – the human face of climate change	
	Lightweight mobile tourist huts (1)	
Finland	GIS flood risk management system	
	Adaptation strategies, City of Rovaniemi	
	Climate change vulnerability –Finland	
	Future tourism prospects for Finnish Lapland	
Norway	Adaptation strategies – Floro	
	Adaptation strategies – Sogn og Fjordane	
	Climate change vulnerability – Norway	
	Sogn og Fjordane early warning system	
Scotland	A sustainable fuelled vehicle for a rural community	
	Adaptation games	
	Adaptation strategies: Cairngorms National Park, Glen Urquhart, and upper Spey catchment	
	Climate change vulnerability – Scotland	
	Community-led sustainable flood management	
	Stay and play – selling alternative activities to the winter sports market	
	Wood fuel in the Cairngorms	
Sweden	Adapting a local woodland management plan	
	Adaptation strategies: destination Are and Lycksele	
	Climate change vulnerability – Sweden	
	Destination Are	
	Innovation competition (schools)	

Source: http://www.climatechangeadaptation.info/case-studies/country/greenland.html



Box 1 CCA points of concern – ActionAid in poor communities in some African cities

Table 2 CCA case studies – African poor communities

Country	Case studies	Themes
Nairobi, Kenya	Adaptation strategies include:	Infrastructure (buildings)
	Digging holes around houses before and during floods	
	Building temporary dikes/trenches to divert water away	
	Securing structures with waterproof-recycled materials	
	Relocating to the highest parts of the dwelling that residents think are secure	
	Using sandbags to prevent the ingress of water	
Accra, Ghana	Adaptation strategies include:	
	Using blocks, stones, and furniture to create high places on which to put their most critical valuables during floods	
	Putting goods on top of wardrobes and in the small spaces between ceilings and roofs	
	Sharing high places with others who have no similar safe sites	
Kampala, Uganda	Undertook collective work to open up drainage channels	
	Temporarily moved to lodges and public places like mosques and churches until the water level receded	
	Barriers were built to water entry at the doorsteps and outlets at the rear of their houses to prevent any water from entering their homes and flowed out quickly	
Lagos, Nigeria	Using sand to raise the entire area to a higher level	
	Standard drainage facilities along major streets (within Iwaya/Makoko) would help to solve the flood problem	

Source: Satterthwaite et al. (2007)

Informal settlements in Nairobi that form approximately 50 % of the population specifically responded to the flooding by adaptation strategies. Table 2 exhibits some of these measures of CCA. In contrast, residents in Alajo, Accra, women and children, suffer when the rain and the floods occur which prevent them from moving, and they have to place their children on building roofs, and boats were brought to evacuate them – June and July floods, 2006 (Satterthwaite et al. 2007). In Kampala, similar strategies were adopted by individuals. Some of these measures are highlighted in Table 2.

In Lagos, both those living in informal settlements and representatives of local government believe that clearing the drainage channel running through Iwaya/Makoko would prevent the pooling of water from other parts of the city. The CCA measures in Lagos were also highlighted in Table 2.

As stated in all the cities, residents' responses were typically ad hoc, individual short-term efforts to survive and protect properties and belongings.

Asia's Case Studies: CCA

There are many case studies in Asia that exhibited attempts to climate change adaptation (CCA). The following section highlights some of these case studies mainly in Vietnam and India.

Case Study of Vietnam

In Asia, particularly Vietnam would face losses totaling US$17 billion per year in case of sea-level rise (SLR) of 1.00 m (VNS 2007). This will dramatically increase by 2050, if no adaptation measures are taken (Waibel 2009), but little has been taken due to financial constraints. It has been underlined that the lack of a national and local framework for CCA and coordination among ministries, agencies, and institutions in areas pertaining to CC is among the institutional constraints to implement adaptation planning in Vietnam (Waibel 2009). Limited knowledge on the relationship between CC strategies and the attainment of sustainable development objectives, as well as capacity building on climate change issues among local stakeholders, is also a key obstacle toward adaptation. Based on researches, the potentials and costs of adaptation by industry, settlement planning, and society to climate change are still at an early stage. It was highlighted that Vietnam urgently needs expertise and financial support from the international community (Waible 2008).

Case Study of Indore: India

In Indore, India, flooding is perceived as a natural, seasonal event; hence, many low-income communities and households had taken steps to limit the damage it does as part of CCA. This was mainly applied to households who live on land sites adjacent to small rivers that are also key storm drains and are particularly at risk (Satterthwaite et al. 2007). In this case study, temporary and permanent adaptations to flooding were made by households and small enterprises, including raising plinth levels and paving courtyards, using landfill and materials that resist flooding, choosing furniture that is less likely to be washed away, and ensuring that shelving and electric wiring are placed high up the walls, above expected water levels. Roofing may be unattached to a house, so it can be speedily removed if the structure is in danger of being swept away. Also, flood-prediction and protection systems and contingency plans for evacuating persons and possessions have been developed by residents (Table 3).

In one of the settlements (Shekha Naga), the residents' first response in one of the settlements to the threat of severe floods is an evacuation plan to move the elderly, children, and animals to higher ground followed by (a) electrical goods, (b) other lighter valuables and cooking utensils, and (c) clothes – easily replaced and undamaged by flooding. Additionally, awareness on how to use the state system of compensation for flood damage was aired by residents to enable them to acquire a perverse incentive for them to build houses in the most vulnerable and dangerous areas. All these attempts were made by local residents not the local government (Stephens et al. 1996). Table 2 summarizes the CCA in Indore and other Asian cities.

Latin America's Case Studies: CCA

Many countries in Latin America had taken steps – by several different communities – to CCA, such as El Salvador, Argentina, Peru, Nicaragua, and Colombia. In El Salvador, the difficulties of getting appropriate risk-reduction action for lower-income groups were manifested (Table 4). However, based on interviews and

Table 3 CCA case studies – Asia

Country	Case studies	Themes
Indore, India	Low-income households' adaptation to flooding	Infrastructure (buildings) Risk Management
	Roofing may be unattached to a house, so it can be speedily removed if the structure is in danger of being swept away	
	Raise plinth levels and paving courtyards, using landfill and materials that resist flooding	
	Flood-prediction and protection systems and contingency plans for evacuation	
Baan Mankong, Thailand	Improved housing conditions and infrastructure and services within low-income settlements	
Cavite City, the Philippines	Community-based strategies include:	
	Accommodate sea-level rise by building houses on stilts	
	Strengthening the physical structure of houses	
	Moving to safer places during calamities	
	Placing sandbags along the shorelines	
	Borrowing money from relatives or moneylenders (at very high interest rates)	
	Engaging in alternative income-generating activities locally or in other areas or changing occupation	

Source: Satterthwaite et al. (2007)

discussions with people living in 15 disaster-prone "slum" communities and with local organizations, these difficulties became noticeable. It was recognized by low-income households that most serious risks to their lives and livelihoods were flooding and landslides, lack of job opportunities, and water provision as well as insecurity due to violent juvenile crimes.

Despite that complex range of issues limited their effectiveness such as the individualistic nature of households' investments and the lack of representative community organizations. However, Manizales and Colombia were facing high rates of population growth and environmental degradation. This attempt was part of a larger program that aimed to improve environmental quality and make resource use more sustainable (Satterthwaite et al. 2007). In contrast, Mexico City has given more attention to climate change mitigation through control of air pollution but little toward adaptation to floods.

European's Case Studies: CCA

At the European level, the overall economic impact of water scarcity and droughts in the past 30 years is estimated at EUR100 billion (EC 2007). The average annual impact doubled from 1976 to 1990 to the following 1991–2006, rising to 6.2 per year in the most recent years. Nevertheless, the exceptional drought in 2003 was amounting to the cost of EUR 8.7 (EEA 2010). However, the 2014 IPCC report indicated three key risks from climate change for Europe, but it did not focus on individual countries. These risks are the following:

Table 4 CCA case studies – Latin America

Country	Case studies	Themes
El Salvador	Appropriate risk-reduction action for lower-income groups	Risk Management Infrastructure (water, sanitation, electricity, buildings)
	Households had invested in risk reduction and on average spent 9 % of their incomes pursuing so	
	Measures were taken to lower risks (diversifying their livelihoods or assets that were easily sold, if a disaster occurred)	
	Remittances from family members working abroad were important for many families, especially in providing support for recovery after a disaster	
Manizales, Colombia	Local government acted on:	
	Avoiding rapidly growing low-income populations settling on dangerous sites	
	Households were moved off the most dangerous sites but rehoused nearby, and most of the former housing sites were converted into eco-parks with strong environmental education	
Ilo, Peru	Improvements were made in water supply, sanitation, electricity provision, waste collection, and public space	
Santa Fe, Argentina	Embankments and dikes were created to encounter floods	
Nicaragua	Improving houses in slum and squatters (PRODEL program)	

Source: Satterthwaite et al. (2007)

1. Increased economic losses and more people affected by flooding in river basins and coasts; as urbanization continues, sea levels rise and peak river flows increase.
2. Increased water restrictions. Significant reduction in water availability from river abstraction and from groundwater resources combined with increased water demand (e.g., for irrigation, energy, and industry and domestic use).
3. Increased economic losses and people affected by extreme heat events: impacts on health and well-being, labor productivity, crop production, and air quality.

These findings align well with the UK's own Climate Change Risk Assessment (CCRA) published in 2012, which identified that the biggest challenges in the UK will be flooding and water shortage. Thus, high levels of adaptation can significantly reduce these risks but does not eliminate them.

The Netherlands' Case Study

In the Netherlands, the findings of a project "Climate as Opportunities" that evaluated 100 large infrastructural investment projects related to spatial planning and water management (some in cities) revealed that integrating CC in planned

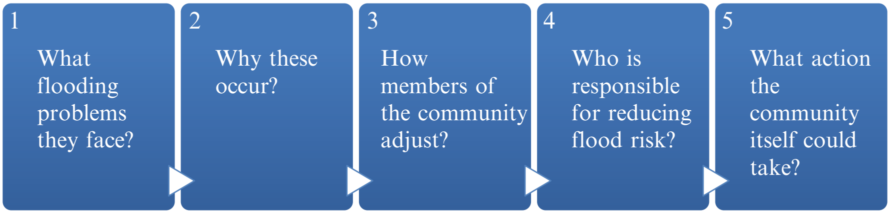


Fig. 10 Adaptation planning in policies (Source: EEA Report 2012)

urban renewal and upgrading projects enhanced sustainability of these projects, hence decreasing the future costs. Figure 10 shows how this was achieved.

Cost of Climate Change Adaptation

Climate change damage is now universally understood that the most significant will be felt in developing countries (Stern 2006), Africa being the continent that causes the most concern. This is mainly due to the reason that their ability to adapt may be limited because of technical, economic, and institutional limitations (Tol et al. 2004). Consequently, economic assessments – integrated assessment analysis – categorize particularly high economic costs from CC in Africa (Downing et al. 2005). As pointed out by van Aalst et al. (2007), conservative estimates are that African economies could be facing losses of at least 1–2 % of GDP or US $10–20 billion annually, though some sectors will be much more exposed.

As highlighted by Watkiss et al. (2010), the potential cost of adapting to climate change in Africa will reach at least US$10 billion but will more likely be in the region of US$30 billion – every year by 2030. Adaptation funding is not a question of aid, it is an international obligation to compensate developing countries for causing damage to their environment, economies, and societies. Developed countries therefore have a responsibility to provide the required adaptation funding immediately through structured financial mechanisms. This finance should be additional to overseas development assistance (ODA).

As indicated in an UNEP study by Watkiss et al. (2010), estimating the costs of adaptation involves a large number of methodological challenges, but perhaps the most significant is the necessity to recognize uncertainty and planning robust strategies to prepare for an uncertain future and not to utilize uncertainty as a reason for inaction. Key findings from the study report the summarized information from the various areas of research from global integrated assessment models (IAMs). These provide aggregated estimates, assessing costs in a single iterative framework. To ensure that this analysis is manageable, they entail simplifications and assumptions but have been the subject of considerable debate. The AdaptCost project commissioned two leading global IAMs, the FUND and PAGE models, to provide results for Africa (Watkiss et al. 2010). Also, it has been stated by Parry et al. (2007) that estimate of the total attributable costs of climate proofing investment to future CC could be a factor of 2–3 higher than the UNFCCC estimates, valued as US$12–28 billion/year by 2030 for Africa. Other studies that count up the additional costs for social protection, to safeguard livelihoods and health related to climate, nevertheless a study by the Grantham Institute (2009) it approximates that an additional US$12–17 billion/year is needed for Africa currently (2015), with this number potentially increasing in future years up to 2030.

From the literature, there are many gaps in the assessment of the full costs of CC compared to that of CC mitigation. Many detailed and comprehensive researches that have been conducted on CC policy are mainly for mitigation, but less was focusing on the assessment of cost. Even with the EU allocating 20 % of funding to climate, the costs and benefits of adaptation are relatively and recently focused on mainly the cost inclusion of adaptation in urban policies, projects, and the cost of actual adaptation measures. Most of the studies such as ClimateCost FP7 and PESETA have looked at the costs in damage terms related to coastal systems, human health, agriculture, tourism, and floods, whereas the cost of heat-related deaths varies according to the methods used (Watkiss 2010; Ciscar et al. 2009). When the "value of statistical life" method is utilized, estimated welfare cost averages will be EUR 30, 102, and 146 billion/year for 2011–2040, 2041–2070, and 2071–2100, respectively (Watkiss 2010). In the USA, the story is similar where little is known about the cost of adaptation.

Studies suggest that adaptation cost could be as high as tens or hundreds of billions of dollars per year by the middle of this century. For Africa, the UNEP has published a report in 2010 estimating the costs of adaptation which involves a large number of methodological challenges, but most essential is the need to recognize uncertainty. It is estimated that due to high uncertainty, the integrated assessment models indicate that the central economic costs of CC could be equivalent to 1.5–3 % of the GDP each year by 2030 and expected to rise over time, with reasonable estimates of around tens of billions of dollars a year by 2030. For example, analysis of sea-level rise in Africa using the DIVA model suggests large impacts and economic costs in coastal zones, but adaptation can reduce these considerably yet has as high benefits when compared to costs; it is estimated at US$1–4 billion/year by 2050. In this respect, low level of investment in some parts of the world led to adaptation shortfall. The Pan African Climate Justice Alliance (PACJA), with the support from Christian Aid, commissioned Practical Action Consulting which developed a report in 2009 with an aim at documenting and analyzing the economic costs of climate change in Africa. It also seeks to contribute to a more detailed understanding of the costs involved for Africa in mitigating and adapting to climate change. Table 5 depicts an outline of possible CC impacts in Africa with adaptation cost ranges (Rebecca, PACJA report 2009).

Costs and benefits of adaptation options were reviewed by UNFCCC, mainly methodological issues for estimating the costs and benefits of adaptation options followed by the economics of adaptation in light of the review. In general, the cost of CC estimates for 2030 which was issued by the UNFCCC has been criticized by Parry et al. (2007). In this study, they looked at the estimates from a range of viewpoints and concluded that key sectors such as ecosystems, energy,

Table 5 Climate change impacts in Africa and adaptation cost ranges

°C rise	1.5	2	4
Cost ranges with adaptation	Minimum US$10 billion a year by 2030 and up to US$30 billion a year, directly in response to climate change		
Cost ranges without adaptation	1.7 % of Africa's total GDP	3.4 % of total GDP	10 % of total GDP

manufacturing, and retailing were not included, yet the additional costs of adaptation have sometimes been calculated as "climate markups" against low levels of assumed investment. Thus, there is a persisting need for detailed appraisals of these costs to care for residual damage. According to the European Climate Adaptation Platform (CLIMATE-ADAPT), the analysis of costs and benefits is vital for assessing feasible adaptation options. A study on the full cost of CC was published by EC-FP7 and coordinated by the Stockholm Environment Institute (2011) highlighted the costs and benefits of CCA.

Planning for urban adaptation is a key approach to reduce the cost of climate change. Improving adaptive capacity is essential in reducing vulnerability of cities to climate-related risk, hence avoids high cost. The IPCC (2007) describes adaptive capacity as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantages of opportunities, or to cope with the consequence." In brief, it is a set of enabling conditions. Adaptive capacity (AC) can be assessed at various spatial levels from national (Yohe and Toll 2002; Greiving et al. 2011; Haddad 2005; Westerhoff et al. 2011) to local. However, economic resources, capital assets, and financial means are vital components of AC (Smit and Pilifosova 2001). It is essential to mention that wealthy nations are in better position to bear the cost of adaptation and plan yet pay for the measures to uphold and increase their capacity when compared with poor cities. While it seems an obstacle for poor nation, little information on the cost of adaptation is available; nonetheless, a small number of options such as flood defenses were reported (EEA 2012).

Making our cities and their infrastructures resilient would definably reduce the cost of CC but would require actions beyond cities borders to be more effective, including adaptation planning (AP). A number of approaches to AP have been established (Smit et al. 2000; Riberio et al. 2009; CBT 2009). Also, the UK Climate Impact Programme (UKCIP) Adaptation Wizard based on "one-step-at-a-time" approach, which is exploited in six adaptation planning steps by the European Climate Adaptation Platform, CLIMATE-ADAPT (EEA and EC 2012). By adopting these steps, as indicated in Figure 11 at earlier stage, the cost of CCA can be significantly lowered. When adaptation planning (AD) is integrated, as one of the drivers into the development of urban policies, AD does not primarily be costly and time-consuming process. Due to the relative recent focus on adaptation, less information was known on the cost of potential climate damage, the cost of inclusion of adaptation in urban policies and projects, and the cost of actual adaptation measures. According to preliminary studies, it has been indicated that

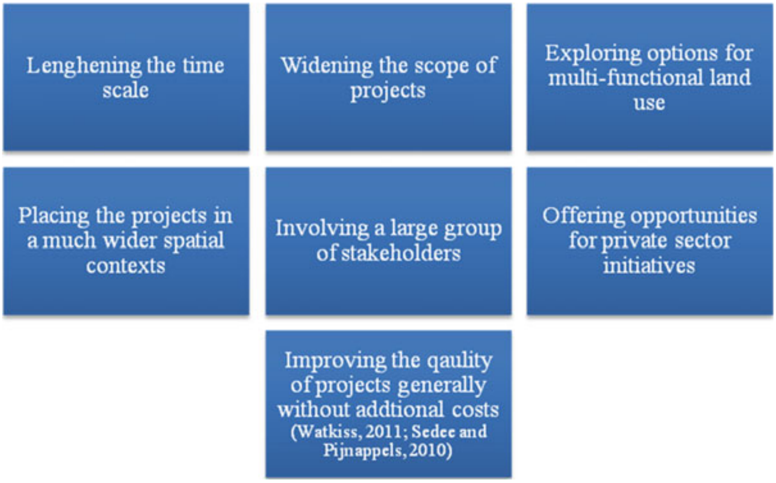


Fig. 11 Adaptation planning steps (Source: European Climate Adaptation Platform (CLIMATE-ADAPT))

benefits often surpass costs. This suggests that if the authorities take advantage of opportunities related to urban renewal, it can result in adaptation benefits surpassing the costs (EEA 2012).

Case Studies of Some European Cities: Affected Regions

To date, most of the studies on adaptation cost have focused on a limited set of easily monetized measures such as floods defenses or other infrastructures. Nonetheless, costing of measures such as greening is more complex. A recent study on green space maintenance and the findings of individual case studies of green roofs in some European cities included in the urban audit database estimated an amount over EUR 7 billion for the first and EUR 100 billion annually for the second, respectively, following a initial investment of about EUR 7 billion (Altvater et al. 2011a, b). The calculations in this study were based around adaptation needs related to current rather than projected climate issues and did not consider the intangible benefits like human well-being, but likewise the estimates for green roofs reflect private and public spending and disregard the savings made. This indicates the importance of taking all costs involved as well as benefits of adaptation options available to estimate their exact economic feasibility.

Mechanism of Financing Climate Change Adaptation

Climate change adaptation funding of actions and measures is essential for development policies in cities and urban areas of vulnerable countries. Most funding in the last decade was mainly directed for CC mitigation. However, financing adaptation to lessen CC impacts varies in developed and least developed countries (LDCs). The latter needs more planning, measures, and funds to adapt to the severity impacts of CC.

Several financial mechanisms exist under the United Nations Framework Convention on Climate Change (UNFCCC) to support adaptation, particularly in low- and middle-income countries.

The UNFCCC Green Climate Fund (GCF) has considered the potential mechanism for mobilizing a share of the proposed international climate financing proposed in the Cancun Agreements and accepted by Parties during the December 2011 conference in Durban, South Africa. The aim of the fund is to support developing countries in their efforts to counterbalance CC via the furnishing of grants and other concessional financing for mitigation and adaptation projects, programs, policies, and activities. Contributions from donor countries and other sources, including both innovative mechanisms and the private sector, will assist in capitalizing such fund (Lattanzio 2013).

The GCF supplements many of the existing multilateral CC funds, e.g., the Global Environment Facility (GEF), the Climate Investment Funds (CIF), and the Adaptation Fund (AF). Nonetheless, the GCF is the official financial mechanism of the UNFCCC; some parties believe that it may eventually replace or subsume the other funds. While many parties expect capitalization and operation of the GCF to begin shortly after the November 2013 conference in Warsaw, Poland, many issues remain to be clarified, and some involve long-standing and contentious debate (Lattanzio 2013).

Also, the UNFCCC listed rich countries with a manifested obligation to assist poor countries to adapt to CC, particularly small-island states and LDCs (id21 Insights 2004). The CCA funds were established as early as 2001 during the UNFCCC Seventh Conference of Parties (Marrakech, Morocco). These funds are shown in Fig. 12.

In terms of effectiveness, the first one (LDCs fund) is the only one that is in operation so far.

Other UNFCCC funds are the "Marrakech Funds" and the Global Environment Facility (GEF) which provides funding for climate change activities (id21 Insights 2004). A special fund of US$50 million for adaptation in developing countries over 3 years has been recently established by GEF. It has been noticed, however, that the GEF rules – they can only be used for the "incremental costs of global benefits" – are considered the barriers to use these funds. Although it is reasonably simple to calculate the costs of global benefits arising from mitigation projects, it is more difficult to do so for adaptation projects (as benefits are usually local rather than global). Nevertheless, the UNFCCC funds are forming a small portion of the financial package that is needed for CCA in the developing nations. In this respect, it is vital to differentiate between adaptation actions and international funding support. The first has to be carried out by vulnerable communities, sectors, and countries themselves, with whatever resources they can provide, whereas the UNFCCC is responsible for international funding support for adaptation in

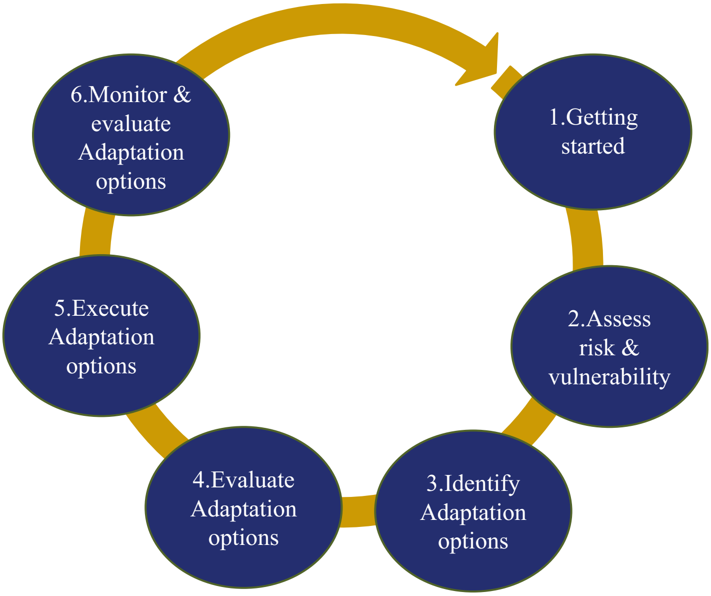


Fig. 12 UNFCCC funds (Source: id21 (www.id21.org))

developing countries. In developing countries, most adaptation will require to be carried out as part of normal development activities. Funding could be secured through bilateral and multilateral funding agencies and through nongovernmental organizations (national and international). These funding mechanisms are shown in Diagram 1. However, it has been stated that a key challenge will be to find ways in which overseas development assistance and UNFCCC funds can be complementary, rather than repeating each other's activities (Huq 2004).

In Asian countries such as Cambodia, Thailand, Lao PDR, and Vietnam, substantial volumes of financing have been noticed. In addition to official development assistance (ODA) and numerous Climate Investment Funds (CIF), such as the Global Environment Facility (GEF) Trust Fund, Special Climate Change Fund (SCCF), and Least Developed Country Fund (LDCF).

Clean Technology Fund (CTF); Strategic Climate Fund (SCF); Asian Development Fund (ADF); the funds from multilateral development and financial institutions such as the Asian Development Bank (ADB), International Fund for Agricultural Development (IFAD), European Commission (EC), and World Bank (WB); bilateral organizations such as the US Agency for International Development (USAID), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Swiss Agency for Development and Cooperation (SDC), Swedish International Development Cooperation Agency (SIDA), Danish International Development Agency (DANIDA), Japan International Cooperation Agency (JICA), and Korea International Cooperation Agency (KOICA); governments of Finland and the Netherlands; the UN; and private sector have been involved in CC adaptation and mitigation efforts. The majority of financing is in the form of grants, technical

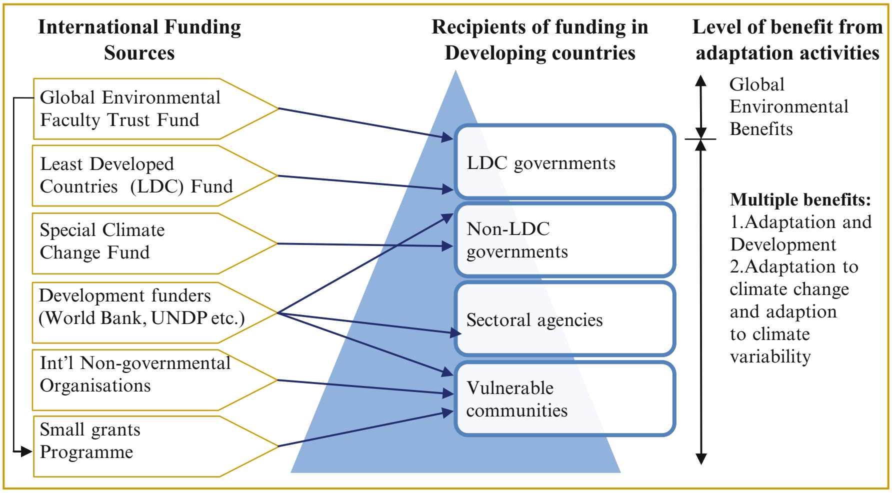


Diagram 1 Entities benefiting from international funding sources for adaptation (Source: Climate Change Programme, International Institute for Environment and Development)

assistance, and then loans. Majority of the initiatives involve two or more financing mechanisms, with a share of country participation, as well. The region will also be targeted with financing from the emerging global Green Fund and other mechanisms as well in the near future (FAO – TCID 2011).

Information and guidance for the costing of adaptation options, including many major methods and techniques, for adaptation option appraisal and decision analysis in the climate change adaptation have been recently reported such as cost-effectiveness analysis (CEA), the cost–benefit analysis (CBA), and the multi-criteria analysis (MCA). It also presents a comparison between these costing and benefits and techniques (2011).

There is a role of financial mechanisms in spreading risks. As pressure increases on traditional risk-sharing strategies so too does the exploitative nature of money-lenders, particularly during disasters. How people access financial institutions for micro-credit, insurance, and financial services requires further research and documentation, including:

- Micro-finance research to better understand how micro-finance can be linked to larger social support systems that strengthen livelihoods and increase disaster risk resilience rather than increase the risk and debt burden for the poor
- Financial incentives research to identify how risk sharing and risk transfers can be promoted through existing institutional mechanisms in terms of CCA

Climate finance is vital for adaptation and it allows nations to adapt to the severe effects of CC and reduce its impacts. The term "climate finance" simply means local, national, or transnational financing, which could be drawn from public, private, and alternative sources of financing. It is essential to handle CC due to

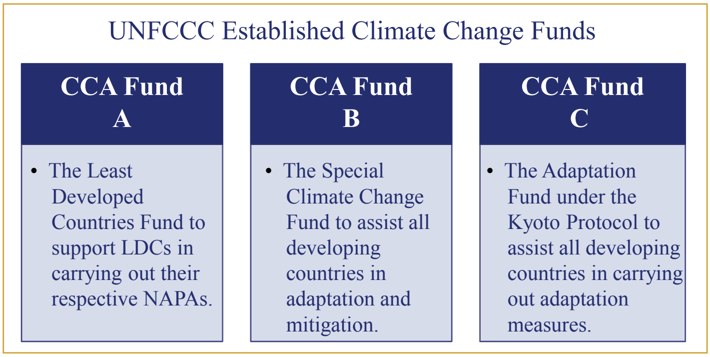


Fig. 13 Programs for financial and technical support (Source: UESPA, GEF, PICCAP)

the fact that large-scale investments are required to significantly reduce emissions, notably in sectors that emit large quantities of GHG. Finance mechanism has been reviewed many times, the latest one was at COP19. This was carried out in accordance with decision 8/COP18, the Standing Committee on Finance (SCF). Expert input was the main focus to the fifth review of the financial mechanism, with a view to review being finalized by COP20. Several initiatives have supported assessments in developing countries. The following programs have provided financial and technical support, with a main focus on capacity building within the scientific and stakeholder communities (Fig. 13).

In the review of the financial mechanism, the objective was to take appropriate measures regarding:

1. Its conformity with the provisions of Article 11 of the Convention and with the guidance of the COP.
2. The effectiveness of the activities it funds in implementing the Convention.
3. Its effectiveness in providing financial resources on a grant or concessional basis, including for the transfer of technology, for the execution of the Convention's objective on the basis of the guidance provided by COP.
4. Its effectiveness in providing resources to developing country Parties under Article 4.3 of the Convention.

A second challenge for those financing adaptations is the need to separate the additional costs of climate change adaptation from "business as usual" development activities. But this is very difficult. In addition, as emphasized above, successful development contributes much to adaptive capacity. Those who want to fund climate change adaptation may want to clarify the difference between risks and vulnerabilities related to climate change and risks and vulnerabilities related to climate variability independent of climate change. From a development perspective, the two need to be integrated. But while the separation may pose many practical challenges, it may be necessary to distinguish between the responsibility (and hence liability) of high-income countries to pay for the damage they have caused (according to the "polluter pays" principle) and funds donated under the banner of philanthropy or charity. For this reason, funding for climate change needs to be in addition to existing aid flows – even if the funding it provides needs to be strongly integrated within development investments. In practice, requirements for detailed additional costs (which are usually virtually impossible to ascertain) are being increasingly waived in favor of approximations.

Another key issue to be resolved is who and what should be prioritized for receiving international funds for supporting adaptation? Should some countries receive priority over others or should some sectors and communities be prioritized? And if so, on what basis? These issues are still under discussion in the UNFCCC and the bilateral funding agencies themselves and have yet to be resolved (Satterthwaite et al. 2007).

Some Remarks on International Fund for Climate Change Adaptation

Most of developing countries, particularly city local governments, ministries, and agencies, have not yet taken climate change adaptation (CCA) seriously within their urban strategies, policies, and investments. Where governments are representative and accountable to poorer segments, they generally have more pressing issues, including large backlogs in provision for infrastructure and services, and much of their population is living in informal settlements where there are little CCA measures. These countries are also under paramount pressure to improve education, health care, and security as well as searching for means of lowering high unemployment rates and eradicate poverty.

Satterthwaite et al. (2007) have argued that unless adaptation to CC is seen to support and enhance the achievement of development goals, it will remain marginal within government plans and investments. Therefore, the need for CCA highlights the importance of strong, locally driven development that delivers for poorer segments and is accountable to them. Similarly, the extreme vulnerability of large sections of the urban population to the many aspects of climate change reveals the deficiencies in "development." He stressed that unless these deficiencies are tackled, there is no real basis for adaptation.

According to the IPCC report in 2014, it is imperative to act immediately. It was stated that actions and choices taken in the early part of this century will shape the risks we face in the latter part of the century. Nevertheless, many of the nations or cities most at risk from climate change lack the political and institutional capacity to address such requirements of adaptation. Even if we can conceive of how this might be addressed, it is difficult to see how existing international institutions, in their current structure, can pursue such tasks. However, early action will allow more time to adapt to impacts, but there are limits to adaptation. Some risks will remain so we cannot rely on adaptation alone. The report also stated that CC will affect all. Poor and rich countries, rural and urban populations alike, must plan for the future and adapt to limit future risks.

Climate change has traditionally received little attention from international donor organizations. A review of 136 projects in Africa funded by the German donor GTZ found no references to climate change (Satterthwaite et al. 2007). International organizations such as the International Monetary Fund and World Trade Organization give little consideration to climate issues in their work. A study by the Organisation for Economic Co-operation and Development revealed the magnitude of development assistance and aid in sectors potentially affected by climate risks (OECD 2003). In Egypt and Bangladesh alone, from 1998 to 2002, between US$1 billion and US$2 billion was directed to sectors affected by climate change and climate variability. As much as 50–65 % of development aid in Nepal was given to climate-sensitive sectors.

Clearly, international donor agencies need to assess the extent to which their investment portfolios in low- and middle-income countries might be at risk due to climate change and take steps to reduce that risk. This is increasingly recognized, and several bilateral and multilateral development agencies and NGOs are starting to take an interest (Agrawala 2004).

At least six development agencies have screened their project portfolios both to ascertain the extent to which existing development projects consider climate risks or address vulnerability to climate variability and change and to identify opportunities for incorporating climate change explicitly into future projects. Donor agencies and NGOs that have started to examine their investment and project portfolios in this way include the World Bank in India; the UK Department for International Development (DFID) in India, China, and Kenya; the Netherlands Department for Development Assistance (DGIS) in Bolivia, Bangladesh, and Ethiopia; the International Institute for Sustainable Development (IISD); and the International Union for Conservation of Nature (IUCN). Most agencies already consider climate change as a real but uncertain threat to future development, but they have given less thought to how different development patterns might affect it.

Conclusions

“A global human-induced climate change has begun, acknowledging the inertia and the next to irreversibility of the climate system, and the likeliness that the response by the global community will not be quick, are strong arguments for concluding that the ongoing change of the climate might be a more serious matter for the future than so far has generally been considered to be the case. Considerably more far-reaching measures during the next commitment period after 2012 than agreed in Kyoto are likely to be necessary in order to avoid serious consequences of a change of climate” (IPCC 2007). Major challenges surround the equity issues of CC, particularly between developed and developing countries, in terms of historically unequal emissions of GHGs, constraints on future emissions, and unequal exposure and capacity to **adapt to the effects of CC**. To address the climate change issue effectively, it must be viewed as an essential part of our efforts to have a sustainable development. Rich countries, partly so, because of their access to valuable resources, must take on a particular responsibility. Also, a more equitable world is necessary and will be to the advantage of everybody, rich and poor, north and south. Otherwise a major irreversible climate change will certainly hit us all.

Climate change is already having an impact on ecosystems and man on all continents and across the oceans. Evidence has grown since the last IPCC report in 2014. As sea levels rise, coastal communities worldwide will experience ever more flooding, coastal erosion, and submergence. Unmitigated climate change poses great risks to human health, global food security, and economic development. Urgent action to reduce emissions is essential to avoid dangerous climate change. The level of adaptation required is dependent on the scale of mitigation. Adaptation is essential to deal with the risks of climate change, but there are limits to what adaptation alone can achieve.

It has been seen that many courtiers are affected and others will be impacted by CC. It is clear that many areas and cities are currently manifesting CC impacts and vulnerable to many risks. But due to poverty, little has been taken for CC adaptation. This left the gap between rich and poor countries widening. Unless real confined measures and policies supported by proper funding (not on paper but materialized) **are enacted on the ground, more risks of CC impacts will be witnessed and manifested; by then, it will be too late to probably act.**

The review shows that climate change adaptation (CCA) is not at the same pace of climate change mitigation (CCM). Thus, more collective efforts are urgently needed at local, regional, and national level. These efforts must be coordinated and successful case studies in similar countries with the same risks and vulnerability should be exchanged.

Despite the fact that there are a bundle of finance mechanism and funding grant to adapt to climate change, more funds are needed mainly in developing countries to lower the gap between the actions, measure, and policies and institutional structure and capacity building.

Reasons for Poor Countries Being Unable to Cope With the Required Adaptation Measures

When considering adaptation, it is easy to get lost in the details of what needs to be done – or in producing “cost–benefit” ratios for nations or regions that do not consider who bears the costs and where they are concentrated. Some examples were noted above of cost–benefit ratios suggesting that certain key cities were unviable – including cities that are central to the current and future development prospects of whole nations.

Discussions of adaptation must also remember the profound unfairness globally between those who cause climate change and those who are most at risk from its effects (Huq et al. 2007). This can be seen in three aspects: first, in regard to people, it is the high-consumption lifestyles of the wealthy (and the production systems that meet their consumption demands) that drive climate change. It is mostly low-income groups in low- and middle-income nations with negligible contributions to climate change who are most at risk from its impacts. Second, in regard to nations, it is within the wealthiest nations that most greenhouse gases have been emitted, but mostly low- and middle-income nations that are bearing and will bear most of the costs. Third, in regard to cities, larger companies and corporations can easily adjust to new patterns of risk induced by climate change and move their offices and production facilities away from cities at risk. But cities cannot move. And all cities have within them the homes, cultural and financial assets, and livelihoods of their inhabitants, much of which cannot be moved (Satterthwaite et al. 2007).

There are figures to show the dramatic differences between nations in average contributions per person to greenhouse gas emissions – for instance, the 80-fold difference between that of the USA and many low-income nations. But these actually understate the scale of these differentials. Greenhouse gas emissions in high-income nations are kept down by the fact that they import many of the energy-intensive goods used or consumed by their citizens and businesses. In addition, a concentration on comparing "averages" for nations obscures just how much the problem is driven by wealthy groups. The differentials in greenhouse gas emissions per person between rich and poor groups can be much larger than the differentials between rich and poor nations. For instance, the greenhouse gas emissions generated as a result of the high-consumption lifestyle of a very wealthy person or household are likely to be hundreds of thousands or even millions of times more than that generated by many low-income households in low-income nations (Hardoy et al. 2001; Hardoy and Pandiella 2007).

The key issue is how to build resilience to the many impacts of climate change in tens of thousands of urban centers in low- and middle-income nations. According to Satterthwaite et al. (2007), such measures should:

- Work with the reduction of risks from other environmental hazards, including disasters (noting the strong complementarities between reducing risk from climate change, non-climate change-related disasters, and most other environmental hazards)
- Be strongly pro-poor (most of those at risk from climate change and from other environmental hazards have low incomes, which limits their autonomous adaptive capacity)
- Build on the knowledge acquired of reducing risk from disasters in urban areas
- Be based on and build a strong local knowledge base of climate variabilities and of the likely local impacts from climate change scenarios
- Encourage and support actions that reduce risks (and vulnerabilities) now, while recognizing the importance of measures taken now to begin the long-term changes needed in urban form and the spatial distribution of urban populations to reduce vulnerability to risks that may become manifest only several decades in the future
- Recognize that the core of the above is building the competence, capacity, and accountability of city and sub-city levels of government and changing their

relationship with those living in informal settlements and working in the informal economy – and the importance within this of supporting civil-society groups, especially representative organizations of the urban poor (this is also to avoid the danger of "adaptation" providing opportunities for powerful groups to evict low-income residents from land they want to develop)

- Acknowledge that government policies must encourage and support the contributions to adaptation of individuals, households, community organizations, and enterprises;
- Recognize the key complementary roles required by higher levels of government and international agencies to support this (and that this requires major changes in policy for most international agencies that have long ignored urban issues and major changes in how adaptation is funded)
- Build resilience and adaptive capacity in rural areas – given the dependence of urban centers on rural production and ecological services and the importance for many urban economies and enterprises of rural demand for (producer and consumer) goods and services
- Build into the above a mitigation framework too (if successful cities in low- and middle-income nations develop without this, global greenhouse gas emissions cannot be reduced)

The very survival of some small-island and some low-income nations (or their main cities) is in doubt as much of their land area is at risk from sea-level rise, yet their contributions to global greenhouse emissions have been very small. There are also tens of millions of people in low- and middle-income nations whose homes and livelihoods are at risk from sea-level rise and storms, although they have made very little contribution to global warming. The economic cost of losing certain cities for which adaptation costs is too high may be relatively small for national economies. But what will happen to international relations as increasing numbers of people lose their homes, assets, livelihoods, and cultural heritages to climate change-related impacts – especially when the main causes of this are strongly associated with the lifestyles of high-income groups in high-income nations – and the reason for their loss is the failure of high-income nations to cut back their emissions? The current Kyoto Protocol requires only industrial countries to cut their greenhouse gas emissions. But, since 1992, governments have been negotiating a new treaty which will ask all countries in the World, industrial and developing countries, to cut their greenhouse gas emissions by 2015.

Adaptation plans must not in any way slow progress toward mitigation. It is obvious that adaptation will be easier and cheaper if greenhouse gas emissions are reduced – so both the amount of adaptation and the rate at which it must be implemented are lessened. Adaptation plans must also bring benefits to the billion urban dwellers currently living in very poor-quality housing, in tenements, cheap boarding houses, and illegal or informal settlements. These billion people include a large part of the population whose homes and livelihoods are most at risk from climate change. A technology-driven, market-led response to climate change does little for them.

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Climate Change and Gender: Study of Adaptation Expenditure in Select States of India

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Contents

Abstract

India is currently executing the National Action Plan on Climate Change (GoI. National Action Plan on Climate Change. Prime Minister's Council on Climate Change, New Delhi, 2008), and subsequently the states have been asked to formulate the state-specific action plans to integrate the national objectives and to implement specific climate change measures. Several questions arise on the impact of mission-mode adaptation policy interventions on enhancing the capacities of women to cope with climate vulnerabilities. Gender is a

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crosscutting issue, and it is well established that climate change affects women disproportionately more than men due to inequities in accessing resources and opportunities to enable them to adapt to the inevitable impacts of climate change, as well as due to the roles that they play and the responsibilities that they shoulder. Addressing gender concerns in the context of climate change requires engendering the government-led adaptation strategies, supported by requisite budgetary outlays. So far the gender budgeting framework has not looked into the aspect of climate change impacts on women. In order to fill the research gaps, the paper attempts to bring forth the analytical interlinkage between gender and climate change by analyzing critically the budgets of select states of India – Uttarakhand (UK), Uttar Pradesh (UP), Madhya Pradesh (MP), and West Bengal (WB). The paper attempts to quantify the public expenditure on adaptation to climate change for the select states and the priority accorded to addressing gender concerns in the various sectors within the overall adaptation framework.

Keywords
Climate change • Adaptation expenditure • Gender-responsive budgeting

Introduction

It is now “unequivocally” established through global scientific assessment (IPCC 2007) that climate change is happening and it is happening at a rapid pace. In congruence with the global-level monitoring and assessment, India carried out a country-specific scientific assessment of climate change impacts on India (GoI 2009). The results point to the need for formulating a national level policy to adapt to and mitigate the effects of climate change (GoI 2008). The first ever country-level policy document, National Action Plan on Climate Change, was a result of this process, which maintains categorically that “climate change may alter the distribution and quality of India’s natural resources and adversely affect the livelihood of its people. With an economy closely tied to its natural resources base and climate-sensitive sectors such as agriculture, water and forestry, it may face a major threat.” As India is an agrarian economy with 70 % of its population residing in rural areas and dependent on agriculture and allied activities for livelihood (GoI 2012, p. ii), addressing the impacts of climate change is necessary to ensure food security and viable livelihood options for the vast majority of its population. Also important is to note that women form larger stakeholders in this sector due to increasing feminization of agriculture and their specific needs and vulnerabilities need to be taken into account when formulating the concerned policies.

The degree of climate vulnerability on large segment of society makes a stronger case for “planned adaptation” interventions. It is because reversal of the wheel of carbon accumulation through mitigation measures takes considerable period of time. Adaptation hence is a natural choice of coping with the irreversible changes (Panda 2011). “Adaptation,” as a multidimensional concept (IPCC 2007;

Bosello et al. 2009; Lim Bo and Spanger-Siegfred 2005; Smit and Pilifosova 2001; Smithers and Smit 1997), refers to coping strategies at the national and local levels such as modifications in the behavior and responses of individuals to adapt to changes in their immediate natural and socioeconomic systems induced by climatic variability. As per the IPCC (2007), adaptation is a well-thought-out effective tool to address various impacts resulting from global warming, already unavoidable due to past emissions and future emissions that might go unchecked. Stern Review (2006) further confirmed the proposition that the benefits of strong, early action on climate change outweigh the costs. Effective "planned" adaptation actions are contingent upon the development and optimal utilization of the resources and developmental programs earmarked for building human and adaptive capacities of the poor and marginalized communities, considered as frontline vulnerable groups to the effects of climate change.

Gender in Adaptation Framework

The process of climate change and the policies and programs in place to deal with it have gendered impact. It is widely acknowledged that the process of climate change would affect women more adversely than men. Women suffer more from the potential impacts of climate change due to limited resources that they possess, the differential role that they play, and the responsibilities that they shoulder within the household as well as in the society (IUCN 2007; Terry 2009a). Women are seen as primary caregivers in the society. They are responsible for the provision of basic needs of the family like health; collection of water, firewood, and other natural resources; food provision; subsistence farming; etc. (Rodenberg 2009; Brody et al. 2008; Masika 2002). Since these are inherently linked with the process of climate change and are bound to be adversely affected in the process, they have a direct bearing on the responsibilities carried out by the women.

Moreover, in the wake of climate change-induced hardships, men often migrate to urban areas in search of better livelihood opportunities, leaving women behind to cater to not just the household needs but also to look after farming for livelihood at home (Roy and Venema 2002; Masika 2002; Terry 2009b). Lambrou and Piana (2006) have stressed on the gendered nature of climate change and its impacts. Women bear the burden of caring for the sick, and because increased levels of sickness are expected to result from climate change, women will bear the costs of climate change disproportionately. Kapoor (2011) has also shown that the process of climate change affects women more adversely than men. In a detailed analysis on the potential impacts of climate change on men and women, she has outlined how climate change has a gendered impact, leading to an increase in the hardships faced by women in terms of an increase in their work burden, drudgery, worsening of their nutritional status, increase in the incidence of trafficking and violence against them, a rise in indebtedness, as well as deteriorating their livelihood opportunities. Nellemann et al. (2011) note that "the process of climate change is the most likely to increase the existing inequalities in the society due to socially constructed gender role."

Ahmed and Fajber (2009, p. 35), in the case study of drought-prone villages in Gujarat (India), identified various systems which enable poor women and men to adapt to climate change in autonomous and planned ways like the "social and power relations that facilitate access for different socio-economic groups, men and women, including rights and entitlements to productive resources or assets (land, water, labour, credit), social networks, capacity-building, and the transfer of new knowledge to support livelihood diversification. Governance considerations, such as accountability, transparency, and the informed participation of vulnerable women and men in community decision-making on disaster management, are equally important to ensure that those directly affected can negotiate access to discussions and decisions, and ultimately build their capacity to adapt." In the case study of Andhra Pradesh, Lambrou and Neson (2010) observed that there were changes in key aspects of farming activities over the last past 30 years with the changes in climate variability. Further, the changes had led to increased workloads, but in different areas of work according to gender. The study also found that the climate change has led to an increased pressure on women to provide food, workload at home, health problems, as well as fights or arguments among the family members.

The above analytical framework calls for certain gender-responsive adaptive policy actions. There are only a handful of studies which have focused on the fact that women, with their intrinsic knowledge about the environment, can contribute more to the process of adaptation (Lambrou and Piana 2006; Denton 2004, 2010; Alber 2011). Lambrou and Piana (2006) argue that "focusing solely on vulnerability may be misleading since women often have untapped skills, coping strategies and knowledge that could be used to minimize the impacts of crisis, environmental change and disasters." In reality, "women have a key role in development, and any potential environmental policy should take cognizance of women as key players particularly given their role as natural resource managers."

Brody et al. (2008, p. 13) have highlighted that "women have a great deal of knowledge and experience in coping with the impacts of climate change and understand their own needs and the types of interventions required for ensuring more sustainable agricultural processes in the face of these changes." Citing a participatory research project on the role of women in rural communities in adapting practices in the Ganga river basin in Bangladesh, India, and Nepal to secure their livelihoods in the face of changes in the frequency, intensity, and duration of floods, Brody et al. (p. 13) concluded that the women were not only clear about what they needed in order to adapt better to the floods, crop diversification, and agricultural practices but also about the skills and knowledge training required to learn about flood- and drought-resistant crops and the proper use of manure, pesticides, irrigation, and so on.

Denton (2004, 2010) also observed that there is a need to go beyond highlighting the vulnerability aspect where the women are concerned. There is a need to recognize women as agents of change in adaptation strategies and involve them in the process of planning at all levels. Engendering of the planning process requires recognition of the importance of women in the adaptation and planning and dedication toward incorporating some basic principles of equity in our processes.

Alber (2011) has put forward two arguments as to why gender issues need special attention in the climate policies. To quote him, "Firstly, both women and men need to be equally and meaningfully involved in planning and decision-making. Secondly, gender mainstreaming as a tool to assess the different implications for women and men of planned legislation, policies and programmes is required in all areas and at all levels, including climate policy. Thus working toward gender equity as an issue in its own right needs to be taken into consideration in all policies, and thus also in climate policy."

Mainstreaming "gender" in the climate discourse asks for specific policy efforts to enhance the adaptive capacities of poor and marginalized sections of women to cope with the uncertain climate vulnerabilities. An important policy instrument available with policy planners is gender-responsive budgeting (GRB). Globally GRB has come to light as an important tool in the ongoing struggle to make the government budgets and policies more gender responsive. The current profile of gender budget statement (GBS) in India (see Box 1) is yet to address the effects of climate vulnerabilities on women. Gender budgeting, as being carried out at the level of the Union Government of India as well as certain states which have adopted GRB, remains a limited exercise, whereby it has become an ex post reporting exercise rather than a process of engendered planning (Parvati et al. 2012; Mishra and Sinha 2012; Jhamb et al. 2013; GoI 2007). This does pose serious limitations in using it as an effective tool to address the gender-based challenges in the face of climate change.

Explaining Adaptation Expenditures in Indian Context

Since 2008, to mainstream the national policy measures in national planning and development, all the states were urged to make their prospective State Action Plans on Climate Change (SAPCCs) to integrate the national goals into their planning measures. At the Conference of State Environment Ministers held on August 18, 2009, the Prime Minister of the country requested all the state governments to prepare their respective SAPCCs. Many states are currently in the process of preparing their respective SAPCCs. "The State Action Plans include strategies and a list of possible sectoral actions that would help the states to achieve their adaptation and mitigation objectives. The common thread that binds all the state actions plan together is the principles of territorial approach to climate change, sub-national planning, building capacities for vulnerability assessment and identifying investment opportunities based on state priorities. This framework provides a broad, systematic, and step-wise process for the preparation of the SAPCCs and advocates for a participatory approach so that the states have ownership of the process and final plan. The major sectors for which adaptation strategies envisaged are agriculture, water, forests, coastal zone and health" (GoI 2013, p. 256).

According to the constitutional agenda of the country, states and centers are collaborators and partners in quasi-federal framework. Pertaining to the resource mobilization and expenditure, while the capacities of both the stakeholders are comparatively similar, the position of the states in effective policy and program implementation is stronger than the central government. Besides implementing central government programs, states implement a range of programs under the state plans to meet the developmental deficits, which are specific to the respective states. For the adaptation measures, hence, the role of the states is significantly paramount as it requires a multipronged targeted and locally contextualized approach to address the specific vulnerabilities prevalent in each state. Since the adaptation measures need to be implemented at the local level within the states, the states themselves can best decide on the prioritization between the various sectors to build the adaptation capacity of the poor and marginalized groups.

The adaptation interventions in India are placed within the broad developmental paradigm. The character of public expenditure till date is to support national policies pertaining to poverty eradication, accelerating the socioeconomic development to meet developmental deficits, and helping the country to build institutional and economic capital. However, mere fulfilling economic growth and poverty reduction are not sufficient to raise the living standards of people to help them adapt to climate change and transforming their lives to adapt to low-carbon lifestyles.

Public expenditure for adaptation strategies requires a new definition. It explains as that expenditure which builds human capacity of the poor, marginalized, and vulnerable groups to meet/cope with the effects of climate change. Developmental budgets are not adaptation budget by itself; it may not be necessarily targeted to build the resilience of the communities. Adaptation expenditure can be viewed as pro-climate developmental interventions at different levels of the economy. It entails improving human conditions and capabilities, enhancing the standard of living for the poor and marginalized groups to prepare themselves to cope with the adverse impacts of climate change. Further it has components of improving sustainability of ecosystem which intends to manage the human dependence on nature and environment, focusing on sustainable use of natural resources, conservation of common property resources and ecosystems, reduction in human-animal conflicts, and creation of buffers against potential natural calamities. It further requires recognizing the multidimensional nature and complexity of the issues involved and necessitates differentiation between programs/schemes that address adaptation to climate change on the lines of their intended outcomes, particularly those that address and augment human capabilities and schemes, which focus on better management of natural resources.

Explaining adaptation expenditure in the overall public expenditure is methodologically a challenging exercise. No such systematic accounting exercise was initiated by the Ministry of Finance (MoF) or Ministry of Environment and Forest (MoEF) to try and assess the public expenditure being spent on addressing the environmental concerns. However, the Union Government for the first time claimed in NAPCC that it spends nearly 2.6 % of GDP toward adaptation expenditure (GoI 2008, p. 19). The basis of such accounting exercise is yet to come in the public domain. But what the policy document NAPCC unveiled was the adaptation policy framework for the country, underlining the focus areas of interventions, viz., crop improvement, drought proofing, forestry, water, coastal region, health, risk financing, and disaster management. In order to demystify the puzzle of adaptation spending in the country, the study by Ganguly and Panda (2010, p. 11) attempted to provide certain classifications of adaptation expenditure in India which was further put into context on the following indicators by Kapoor and Panda (2014) in the analysis of state funding:

- *Land development*, *drought proofing*, *irrigation*, *and flood control* including programs like the Drought-Prone Areas Program and the Integrated Watershed Management Program
- *Agriculture and allied activities* including programs like the National Food Security Mission and Macro Management of Agriculture (MMA), ATMA, National Horticulture Mission, and Dairy Development programs
- *Water resources* including programs like the Desalination Project and Artificial Recharge of Groundwater Through Dug Wells
- *Forestry*, *wildlife*, *and biodiversity* including programs like the Integrated Forest Protection Scheme and the Integrated Development of Wildlife Habitats
- *Poverty alleviation*, *livelihood promotions*, *and food security* including programs like the food subsidy, Antyodaya Anna Yojana and Swarnajayanti Gram Swarozgar Yojana (now changed to National Rural Livelihoods Mission)
- *Risk management* including programs like the National Agriculture Insurance Scheme (NAIS) and Weather-Based Crop Insurance
- *Disaster management* including programs like the National Disaster Management Program and the Tsunami and Storm Surge Warning System

Methodological Boundary

The study of adaptation expenditure necessitates the process of identification of the schemes and programs oriented and enabled with building the resilience of the people and the state against the adverse impacts of climate change. This premise is based on the primary assumption that the certain initiatives undertaken by the government for general development also build resilience of the communities to deal with the adverse impacts of climate change and also induce behavioral changes in use of and access to natural resources. The study of adaptation expenditure of the state budgets through gender lens requires the analysis of financial data that are reported on many levels. Funds for adaptation expenditures are flowing through centrally sponsored schemes (CSS), central sector schemes, state plan schemes, and district sector plans. The study has attempted to capture the funds flowing to these categorizations of programs.

The time period for analysis for estimating expenditure is 4 years from 2009–2010 (actuals) to 2012–2013 (budget estimates). The states identified for the study are Madhya Pradesh, Uttar Pradesh, Uttarakhand, and West Bengal. For the identification of the schemes/programs pertinent to adaptation to climate change, authors have relied extensively upon the SAPCCs, annual reports of the departments, plan documents, and policy guidelines of the ministries and departments to cull out the relevant information about various components within each scheme that aims to build/increase the adaptive capacities of the people and the state. In addition to, for expenditure tracking, extensive and meticulous research of state budgets and plan budget documents of the states has been undertaken to arrive at the quantum of expenditure that state government is spending for adaptation to climate change. Field studies in the study states have become significant instruments to elicit the perspectives of the government officials on adaptation interventions and expenditures, the SAPCCs, impacts of climate change on women, and finally knowing the prospective plan for the future. Centre for Budget and Governance Accountability (CBGA) with the collaboration of Alternative Futures has been part of a series of Interdepartmental Round Table 1 Discussions on climate change, which has been a forum of immense help to capture insights from the multi-stakeholders participation.

Table 1 Estimations of adaptation expenditures of select states in India

State	Public expenditure on adaptation to climate change	2010–2011[a]	2011–2012[b]	2012–2013[c]
Madhya Pradesh (MP)	Total adaptation expenditure (million in US $)	14,848.00 (32.82)	16,822.00 (35.10)	17,884.00 (32.88)
	Total adaptation expenditure as % of total budgetary expenditures (TBE)	22.55	20.86	22.35
	Total adaptation expenditure as % of GSDP at current prices	5.7	5.33	4.36
Uttar Pradesh (UP)	Total adaptation expenditure (million in US $)	24,188.00 (53.47)	23,307.00 (48.64)	32,335.00 (59.44)
	Total adaptation expenditure as % of TBE	17.75	14.1	17.36
	Total adaptation expenditure as % of GSDP at current prices	4.03	3.43	4.2
Uttarakhand (UK)	Total adaptation expenditure (million in US $)	1,158.49 (2.56)	1,402.64 (2.93)	1,489.92 (2.74)
	Total adaptation expenditure as % of TBE	7.87	8.03	6.42
	Total adaptation expenditure as % of GSDP at current prices	1.38	1.49	1.38
West Bengal (WB)[d]	Total adaptation expenditure (million in US $)	8,137.15 (17.99)	11,032.51 (23.02)	13,454.17 (24.73)
	Total adaptation expenditure as % of TBE	**11.15**	12.54	13.4
	Total adaptation expenditure as % of GSDP at current prices	**1.76**	2.07	2.16

Source: Authors' calculation of adaptation expenditures from State Budget Documents (various years); Annual Plans Documents of study states (various years)
[a]Annual average of exchange rate of INR to US $ in FY 2010–2011 (45.24)
[b]Annual average of exchange rate of INR to US $ in FY 2011–2012 (47.92)
[c]Annual average of exchange rate of INR to US $ in FY 2012–2013 (54.40)
[d]The adaptation estimation for West Bengal includes both plan and non-plan expenditures. On the other hand, the adaptation expenditure of other three states includes only plan expenditure components

Analysis of the Budgets of Select States

Following the abovementioned categorization of adaptation program framework, it is observed that there are marked variations in adaptation spending among the four study states due to the extent of developmental interventions. However taking into account the differences in the size of the states and their corresponding economies and total budgetary outlays, it would be misleading to suggest that UP is doing better than the other three states (on the basis of absolute numbers). To make the analysis comparative, the study has computed the total adaptation expenditure (TAE) for each state as a proportion of the gross state domestic product (GSDP), as a proportion of the total budgetary expenditure (TBE), as well as the per capita adaptation expenditure (PCAE).

India is a federal country having 29 states. UP has one of the largest budgets in comparison to any state in India. Its total budget was nearly two crore in 2012–2013 (BE) in which the proportion of developmental and nondevelopmental expenditure was 67 % and 37 %, respectively (RBI 2013). The analysis of adaptation budget for UP revealed that it spent approximately 4.2 % of GSDP (at current prices with 2004–2005 base year) in 2012–2013 (BE) and around 16.2 % as proportion of total budgetary expenditure (TBE),for the same year. MP budget shows similar trend while estimating adaptation expenditure. Its developmental and nondevelopmental compositions of expenditures turned out to be 68 % and 32 %, respectively, during the same year (RBI 2013). However, its share for the adaptation budget was much higher than UP as it constituted nearly 4.8 % of the GSDP (at current prices with 2004–2005 base year) and nearly 22.35 % of its TBE in 2012–2013 (BE). In absolute number, MP spent nearly Rs. 17,000 crore for adaptation-oriented interventions in the FY 2012–2013 (Fig. 1).

West Bengal (WB) and Uttarakhand (UK), as compared to UP and MP, have a small size of adaptation budget. The UK has the smallest state budget under study having a budget of approximately Rs.21,931.77 crore in 2012–2013 (BE), in which the adaptation expenditure is estimated to be merely Rs 1,489 crore in FY 2012–2013. This constitutes nearly 6.8 % of the TBE, and as proportion of GSDP (at current prices with 2004–2005 base year), it is merely 1.38 % (Fig. 1). This reflects the fact that the budget of the UK has placed priority on adaptation measures in the state. The UK is highly vulnerable to climate change impacts due to its geophysical location and because of its almost complete dependence on climate-sensitive natural resources. About 65 % of its area is under forests, and more than half of its population is dependent on agriculture, horticulture, and livestock for their living. Most of the agriculture is rain-fed and so very sensitive to climate vagaries. A whopping 73 % of women workers are engaged in farm-related activities, compared to 40 % of all male workers (Census 2011), but only 10 % of all landholders are women.

The analysis of WB state budget suggests that out of the total budget of approximately Rs. 1 lakh crore, the adaptation budget is nearly 13.40 % of TBE and 2.2 % of the GSDP (at current prices with 2004–2005 base year) in FY 2012–2013 (Figs. 1 and 2). The figure suggests an increasing trend over the

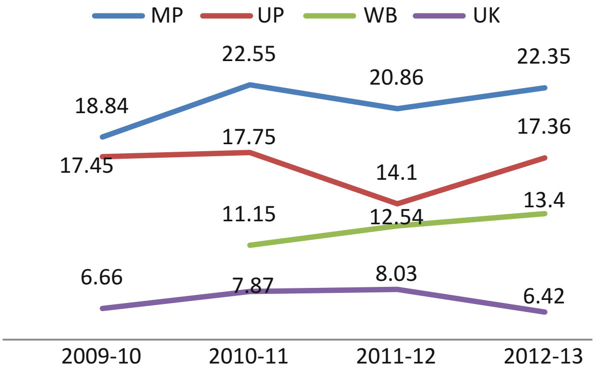


Fig. 1 Adaptation expenditure as proportion to total budget of selected study states

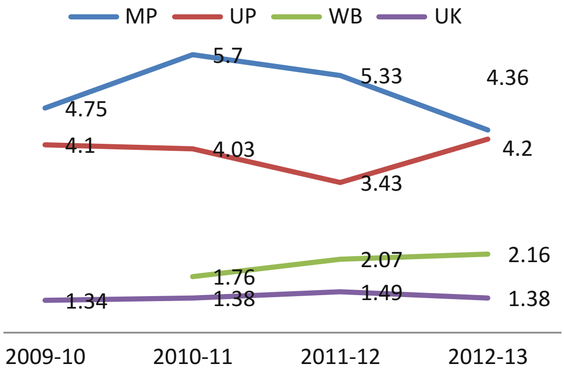


Fig. 2 Adaptation expenditure as proportion to GSDP of selected study states

years. WB being the world's ninth most populated state, with a fifth of its people living below the poverty line (GoI 2013,) has a long history of recurring cyclones and floods. Climate change brings with it the threat of sea-level rise and related disasters. Primary sector workers comprise only 44 % of total workers, but they are extremely resource poor with women comprising only 3.5 % of total land owners.

The total adaptation expenditure by the states has also been computed as per capita adaptation expenditure (PCAE). When one looks at the per capita expenditure on adaptation to climate change (Fig. 3), yet again MP emerges as a better performer as compared to the other three states under analysis. However what is surprising is that in per capita terms, the UK fares better than WB, which is surprising as the outlays for WB are inclusive of the non-plan component as well.

Assessing the Sectoral Prioritization Within the Adaptation Expenditure

While looking into sectoral composition within the adaptation expenditure framework for each state, the study tries to gauge the priority within the adaptation framework and whether adaptation initiatives by the states are more

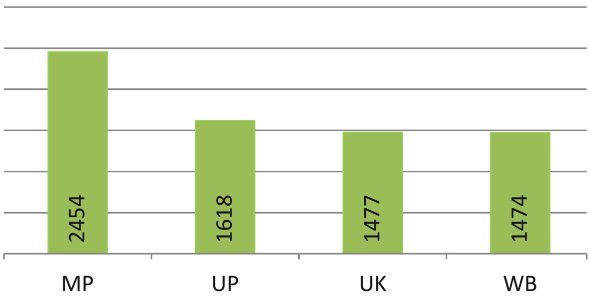


Fig. 3 Per capita state budget expenditure on adaptation to climate change (in Rs.) in 2012–2013 (BE)

pro-developmental or more pro-adaptation in nature. Analysis reveals that in all the four states, poverty alleviation, livelihood, and food security have the highest quantum of allocations, indicative of the high priority accorded to this sector in the states' plan schemes. Also, the allocations under this sector surpass the allocations under other sectors by a huge margin. This is probably owing to the fact that this is one area which is more in the nature of developmental initiative rather than purely adaptation strategies, with many developmental schemes already in place in these states. The adaptation benefits that accrue from this sector are more in the nature of incidental benefits, which nevertheless go a long way in building up the resilience of the people and the state against any adverse condition. In fact, sectoral distribution of adaptation budget in the UK shows that components such as poverty alleviation, livelihood and food security, land development, drought proofing, irrigation and flood control, and agriculture and allied services constitute nearly 80 % of the total adaptation expenditure in the state.

Two areas that need maximum attention are disaster management and risk management. Considering the kinds of threat that climate change portrays, it is important to have adequate mechanisms in place to deal with any natural calamity that may result due to changing climate patterns. The states also need to focus on putting in more effort and thought into how best it can work to alleviate the risk factor that increases with the threat of climate change. Hence both form an important focus area to be given high priority in the overall policy framework for adaptation. Unfortunately, both suffer from lack of adequate prioritization by the government in terms of actual allocations. For example, in Uttar Pradesh, there is no expenditure whatsoever on disaster management, and the forestry sector has been accorded a low priority. Agriculture and allied activities also need greater prioritization, especially in view of the fact that a majority of the population depends on this sector for livelihood as well as for food security. Study reveals that in all the states most of the schemes and programs that make up the adaptation budget in the state are primarily developmental in nature, with adaptation being a secondary incidental benefit. The entire planning approach is focused on "development," and prioritization toward adaptation is missing in all the states. It is quite clear from the analysis that adaptation is yet to be recognized as a policy priority by the government and that most of the adaptation measures are side-along benefits from the mainstream developmental measures (Figs. 4, 5, 6, and 7).

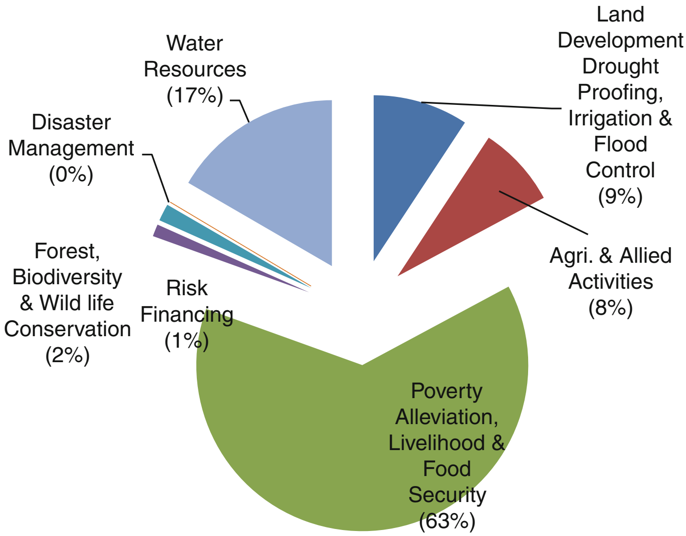


Fig. 4 Adaptation expenditure in FY 2012–2013 in MP

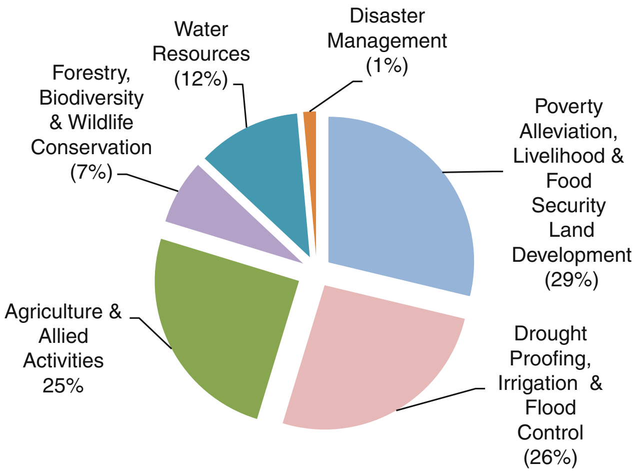


Fig. 5 Adaptation expenditure in FY 2012–2013 in the UK

Engendering Adaptation Budget in Select States

It is important to recognize the fact that in all the categories of adaptation interventions, women are major actors; hence no sector can be viewed as gender neutral. Mainstream developmental programs need to be engendered, taking into account the numerous developmental deficits faced by women and girl children in the

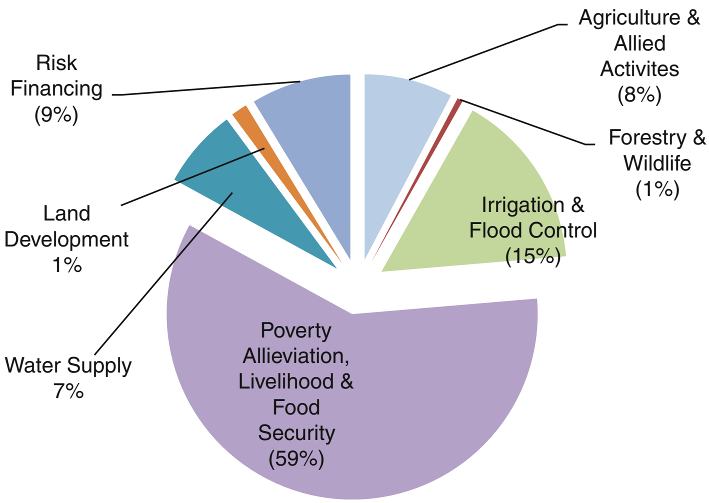


Fig. 6 Adaptation expenditure in FY 2012–2013 in UB

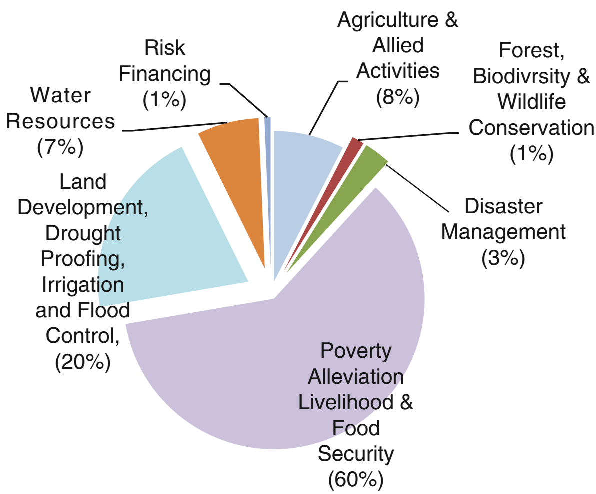


Fig. 7 Adaptation expenditure in FY 2012–2013 in WB

various sectors. Given the scenario with respect to the status of the women in these four states, it is imperative that the gendered concerns in all spheres of development, and particularly with respect to the process of climate change, are recognized by the policy makers and the same addressed in the policies that promote adaptation or mitigation to climate change. To assess the state's endeavors in this regard, the study looked at the gender budget statements/women component plans being compiled in the respective states. Gender budgeting refers to a method of looking at the budget formulation process, budgetary policies, and budget outlays from the gender lens (Das and Mishra 2006). "Gender Budget, with regard to the

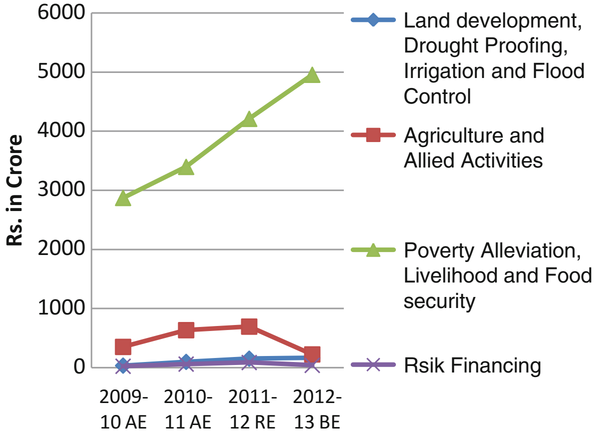
Government at any level, does not refer to a separate budget for women; rather it is an analytical tool which scrutinizes the government budget to reveal its gender-differentiated impact and advocate for greater priorities for programmes and schemes to address the gender-based disadvantages faced by women" (Parvati et al. 2012).

In order to evaluate the priority accorded to women and girl children in the schemes specific to adaptation to climate change, an analysis was carried out of the gender budget statement (GBS)/women component plan (WCP) of the respective states. Schemes reported in the GBS/WCP were identified as adaptation specific or pro-adaptation based on their respective guidelines and policy objectives. The states of MP and the UK have institutionalized gender budgeting and present a gender budget statement as a part of their respective state budgets. However, both the statements suffer from some critical shortcomings which dilute the efforts of the states in this domain. The methodologies followed by both the states are flawed; while MP has been reporting 100 % allocations under various schemes under Part B of the GBS (which is meant to capture at least 30 %, but not entire allocations meant for women/girl children under a scheme), in the UK it is the Finance Department which is single-handedly preparing the GBS without any inputs or consultations with the line departments. Merely reporting higher allocations (the way departments are doing in MP) in the statement has been seen as the final objective by most departments.

There also exist issues with regard to the quality of interventions being reported under the GBS in both the states. Recognizing that the purpose of gender budgeting is to address the concerns being faced by women and girl children, not just in their socioeconomic status but also for their overall empowerment, in most cases, there remain doubts regarding the pertinence of including these interventions under the GBS in both the states. Most of the schemes and programs being reported do not aim to address gender inequity in any way or only continue to reinforce gender stereotypes (Parvati et al. 2012). Moreover, the so-called indivisible sectors remain outside the ambit of the GB statements.

In the sectors identified as crucial for adaptation, departments such as Agriculture and Watershed Management hardly report any schemes under Part A of the GBS in the UK where 100 % of the allocation is for women. Where such schemes are reported, the budgetary allocations under these are miniscule. Moreover, there are some schemes specifically for women that have well-defined guidelines for their benefit, which are not listed in the GBS in the UK. For example, schemes like Mahila Dairy Vikas Yojana and Mahila Dairy schemes being implemented by Dairy Development Department, though exclusively for women, do not find mention in the GB statement. Again, under the GBS, allocations under food security get maximum priority mainly on the account of the centrally sponsored scheme for nutrition. Several key climate change-sensitive sectors like disaster management and risk financing do not report even under Part B of the GBS, where at least 30 % of the total allocation must be for women. In cases where some interventions are reported under the GBS, the allocations under these are fairly low. Above all, interventions being reported under the GBS in these five categories are mainly

Fig. 8 Adaptation to climate change under the GB statement in MP



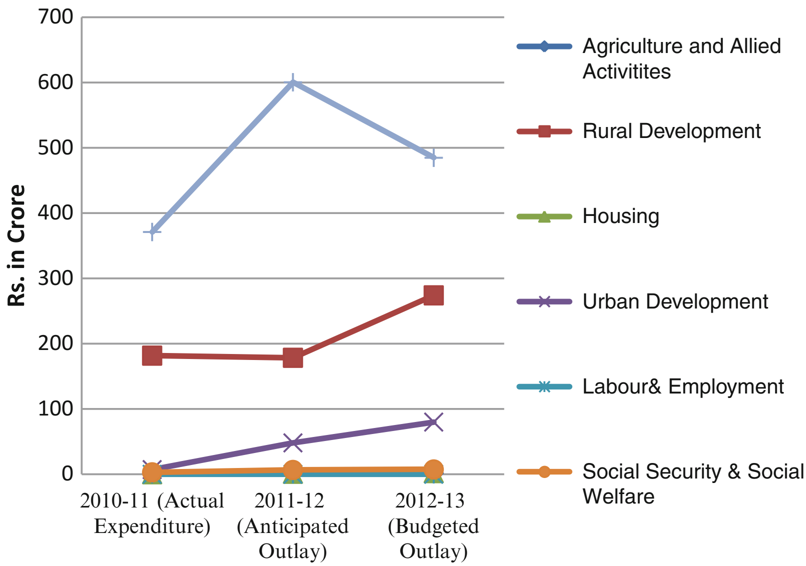
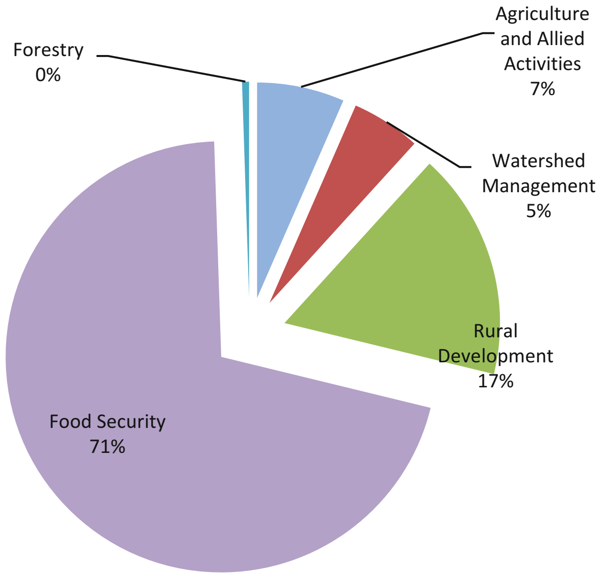


Fig. 9 Adaptation to climate change under the women component plan in WB

welfare oriented; they do not empower people by building their capacities and resilience to various shocks, including climate change (see Figs. 8, 9, 10, and 11).

The analysis of the GBS in MP reveals that very few departments have all-women schemes, and these too have miniscule allocations. Most sectors remain outside the ambit of gender budgeting. In the sectors which do have a component of gender, the bulk of the allocations are concentrated in the poverty alleviation category. Sectors like disaster management and forestry do not report under GBS. Allocations under agriculture sector remain low and have witnessed a falling trend over the last few years. This is a concern, especially in view of increased

Fig. 10 Adaptation to climate change under GB statement in the UK for 2012–2013 (%)



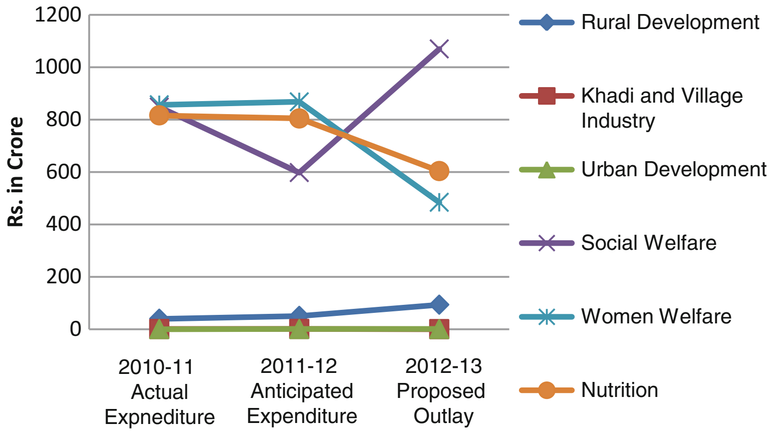


Fig. 11 Adaptation to climate change under WCP in UP

feminization of agriculture. Planning for gender concerns in the budget process is missing with most interventions remaining an ex post exercise by the relevant departments (see Figs. 8, 9, 10, and 11).

The states of UP and WB are still carrying forward the WCP, presented as an annex in their state annual plans. WCP is restricted to the plan budget of the government. Moreover, only select departments, which are considered as women specific and beneficiary oriented, have been reporting under the WCP. Further, even the reporting under this seems more like an ad hoc exercise, rather than a planned, deliberated task. The states in formulating the WCP, have not adopted an "engendering" approach to planning. Many schemes, which have clear policy guidelines benefitting women and are being implemented in the states, do not find mention in the WCP. Uttar Pradesh has still not moved on to adopting gender budgeting as a tool for women's empowerment. The state has in place, since 2005–2006, a WCP which, under plan allocations, reported an outlay of Rs. 2,253.09 crore during 2012–2013 (see Figs. 8, 9, 10, and 11).

The WCP witnessed an increase in the quantum of funds being reported over the recent years. However, no schemes under agriculture and allied activities, which are a core sector with respect to both climate change and the participation of women in the sector, are reported under WCP. In fact the coverage of sectors under the WCP is very restricted, leaving out a bulk of the core sectors that have a direct bearing on the welfare of women. The entire approach poses a question on the seriousness with which the exercise of WCP is being carried out by the planning department. Nutrition and women welfare, critical to cushion the impact of low food production in the wake of climate vagaries, witnessed a sharp fall in 2012–2013 compared to 2011–2012. A reverse trend was witnessed in the allocations under social welfare. In fact, most schemes reported do not address specific gender concerns but seem a procedural ex post accounting exercise. Again, reported schemes are welfare oriented, not empowering. Also, any adaptation benefits that accrue from these are merely side-along benefits.

West Bengal too has not adopted gender budgeting yet. The state presents a WCP which has witnessed a marginal increase in allocations over the last 3 last years (2010–2011 to 2012–2013). Very few departments report under the WCP, and key adaptation-centric sectors remain outside the ambit of the WCP. Reporting under the WCP is not robust with many interventions that benefit women are not being included under the WCP. One disturbing observation that emerges from this analysis is that none of the schemes can be termed as purely adaptation schemes. All of them fall under the head of developmental interventions. Even allowing for the fact that all interventions are not being captured in the WCP, it is quite disconcerting that the mainstream adaptation strategies of the state have not found a place for women and their needs in their planning and budgets.

Finally, it is observed from the field that the whole approach of integrating the gender concerns in the entire planning and budgeting process is missing. There has not been an attempt to think through the challenges that women and girl children face in the context of climate change and the adaptation framework and thereby address them. The recognition of the interlinkage between process of climate change, adaptation to climate change, and the inherent gender concerns is absent. Thus both GBS and WCP have remained fairly limited exercises in these states, each fraught with its own set of anomalies. Moreover, as observed earlier, the interlinkage of gender, climate change, and hence adaptation to climate change is yet to be recognized in the planning framework by all the states. Most of the adaptation benefits remain mainly a spillover from the main developmental initiatives of the states, and at the same time prevalent gender concerns within it have not been integrated in the overall planning in the states.

Box 1: Gender Budgeting in India

Gender responsive budgeting (GRB) has been endorsed as an important tool for advancing gender equity. The latest count shows that around 90 countries have integrated GRB practices and processes. Gender budgeting is based on the premise that there are specific gender-based disadvantages confronting women and girls due to which they are able to derive much less benefit from a given policy as compared to men and boys. A gender-responsive budget thus ensures that such disadvantages are recognized and special measures are taken to address the gender-based disadvantages. Diane Elson has proposed a set of six tools of GRB:

1. Gender-aware policy appraisal
2. *Beneficiary assessments*
3. Gender-disaggregated public expenditure incidence analysis
4. Gender-disaggregated analysis of the impact of the budget on time use
5. Gender-aware medium-term economic policy framework
6. Gender-responsive budget statement

In India, the first attempt to ensure a definite flow of funds to women was with the introduction of Women's Component Plan (WCP) in the Ninth Five-Year Plan. However, noting its sluggish growth and given fundamental shortcomings in its approach, the government discontinued WCP and adopted gender budgeting.

Since 2005–2006, a separate statement "gender budget" (Statement 20, Expenditure Budget Volume I) is presented every year as part of the union budget that tries to capture all those budgetary resources, which, according to the Union Ministries/Departments, are earmarked for women and girls. The schemes with 100 % funds meant for women and girls are reported in Part A of the GB statement, while those with at least 30 % funds but not the entire sum are slated under Part B. A total of 33 demands for grants under 27 ministries/departments and five union territories are covered in the GB statement of 2012–2013.

Source: Parvati et al. (2012) and GoI (2007)

Conclusion

The chapter focuses on the "priority accorded to gender" in adaptation-responsive programs and public budgeting in select states. The developmental planning and policies pursued by the study states fail to empower women to meet the vulnerabilities emanating from climate change. Policies followed by these states are largely gender blind and gender neutral. State-specific action plans on climate change were formulated to integrate that climate change concerns also do not address gender concerns in climate change policies and developmental interventions.

The character of public expenditure in study states is largely developmental and not oriented toward adaptation to climate change. Even within the framework of adaptation expenditure, the focus is largely on interventions toward poverty alleviation, livelihood, and food security. Huge gaps are observed between expenditure for the abovementioned area and climate-sensitive sectors like agriculture and allied activities, water resources, disaster management, forestry, etc. These gaps reveal that India has consistently neglected investing in natural resources which are now vulnerable to climate change impacts. Women, poor and marginalized, are disproportionately dependent on natural resources for their livelihood sustenance. In sum, the gender status quo should be reversed in local planning and budgeting.

For effective assimilation of gender concerns in climate change discourse, policy departure should focus on integrating gender concerns policy planning itself. Mere bringing out of a gender budget statement is hardly effective unless gender budgeting is implemented in its true spirit at all levels of governance, especially in the wake of climate change threats. Further, all states are at the nascent stage of implementing gender budgeting, and often this is an eyewash. It is mostly a mere reporting exercise.

The implementation of NAPCC and state action plans is yet to happen. However without putting gender and poor and marginalized (vulnerable) people at the center of inclusive economic development and adaptation, the challenges of climate change and economic growth can never be addressed.

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Climate Change Mitigation: From Carbon-Intensive Sprawl Toward Low Carbon Urbanization: Progress and Prospects for Istanbul

Arzu Kocabas, Michael S. Gibson, and Murat Diren

Contents

Abstract

This chapter assesses the prospects for progress toward sustainable urban development in Istanbul/Turkey, as an outcome of interrelated innovative policies for climate change mitigation which reduces carbon emissions from cities/towns and earthquake mitigation-led urban regeneration. It first provides a generic model of planning for low carbon cities which integrates "top-down" and "bottom-up" components. This model structures the subsequent analysis of the experience of planning for eco-settlements in EU countries, with particular reference to the UK. Lessons from this experience then inform an analysis of policy development in Turkey at national/local levels, which focuses on climate

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change mitigation action and earthquake mitigation-led neighborhood regeneration programs. A case study of Kartal, Istanbul, demonstrates the application of these policies which have the potential for reducing carbon emissions from Turkish cities through the redevelopment of earthquake-vulnerable, poor-quality, carbon-intensive housing areas and replacing them with low carbon neighborhoods. As the housing stock in Turkish cities contributes over a quarter of national carbon emissions, this will make a major contribution to national carbon reduction targets and help make urban areas earthquake resilient. This assessment has implications for earthquake-threatened cities elsewhere in the world.

Keywords
Low carbon cities • Climate change action plans • Carbon-neutral neighborhoods • Earthquake mitigation • Brighton and Hove • Istanbul • Kartal

Introduction

In July 2011, the Turkish government published the country's national climate change action plan (NCCAP), the product of international collaboration which had enabled Turkish government policy makers to draw on the experience of EU countries, particularly the UK. In common with the national plans of many other countries, the Turkish NCCAP specifies that local municipalities will play a major role in implementation. The UK national climate strategy and action plan is widely regarded as one of the most sophisticated in the EU. The coastal city of Brighton and Hove, 1 hour by train from London, has the national leader of the Green Party as one of its MPs and has the country's only Green Party-led municipal administration. The city's experience illustrates best practice in planning for low carbon cities in the UK. As one of the 32 district municipalities of Istanbul, Kartal is on the Marmara Sea coast, somewhat less than an hour from Istanbul city center. Like Brighton and Hove, Kartal's urban area is between the sea and green hills behind, but green planning is in an embryonic state. In the context of the two countries' evolving national policies, this chapter draws on the experience of Brighton and Hove to discuss how Kartal can develop its climate change and action plan and move further toward planning for low carbon urban development and regeneration.

Toward Low Carbon Urbanization: An Analytical Framework

Since the early 1990s, the growing understanding of the contribution of cities to climate change has stimulated the emergence of the (still contested) concept of "sustainable urban development" (Jenks and Dempsey 2005). This concept has underpinned a variety of normative models of eco-settlements at all levels. For example, the ECOCITY model (Coplack 2003) comprises of compact, pedestrian-oriented, residential, and mixed-use neighborhoods, composed of solar-oriented buildings, and integrated into a polycentric urban system through a low carbon public transport system. But the challenge is how governments can modify market-driven urbanization processes to deliver sustainable urban development.

In the run-up to the 2009 Copenhagen Summit, methods of calculating the sources of carbon emissions improved, prompting growing awareness that cities produce 70 % of global CO2 emissions including 40 % from buildings. Across the EU, some 28 % of carbon emissions come from the housing sector, with slightly less from transport. Planning for low carbon new and extended settlements and neighborhood regeneration is developing in the context of evolving climate change action plans which establish carbon reduction targets as key priorities across a wide range of sector policies, particularly in energy, housing/buildings, and transport – a process known as "mainstreaming." Thus Wilson and Piper's (2010) review of climate change policy frameworks at international, EU, and national levels identified a range of increasingly standard components, many of which relate to the promotion of low carbon urban development, including mitigation through emission reduction, building resilience/reducing vulnerability (related to buildings, communities, infrastructure, and habitats), adaptation programs, legislation/regulation/guidance, mainstreaming, and cross-sectoral policy integration, together with public awareness raising and monitoring the impact of action programs.

But it is increasingly acknowledged that planning for low carbon cities will require a combination of a top-down national framework of policy, law, and finance with a bottom-up capacity for program development and delivery by local municipalities working in partnership with NGOs, the private sector, and increasingly "carbon-conscious" households. In particular, it will be critical to deliver carbon-neutral neighborhoods (CNNs), which can be defined as those in which "... over a year, net carbon emissions from energy use within the neighbourhood and from vehicles based in the neighbourhood, would be neutral" (Gibson 2007, p. 15). Figure 1 illustrates a conceptual process model which integrates top-down and bottom-up action to deliver CNNs, as building blocks of low carbon urban planning. The matrix in Fig. 2 illustrates the key parameters of action planning for CNNs.

The vertical axis of the matrix sets out a range of interlinked neighborhood planning objectives, and the horizontal axis illustrates a range of possible actions to achieve each objective.

Brighton and Hove in its National Context: Toward a Low Carbon City

In England, as in many EU countries, planning for climate change has gathered momentum as it has become increasingly focused on the reduction of carbon emissions from cities and towns, particularly from buildings and transport systems. National government is providing an evolving framework of targets, policies, and resources which are cascaded down to municipal and eventually neighborhood level, as carbon reduction becomes a key dimension of multi-level and

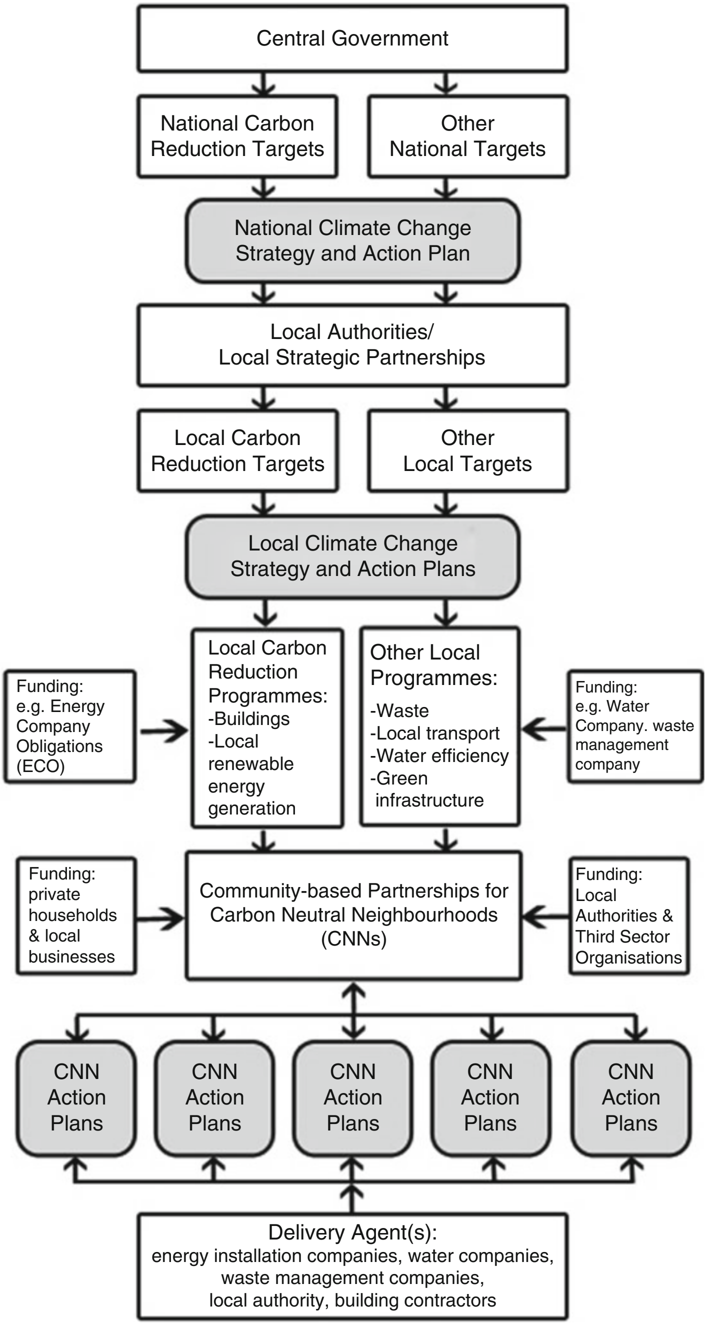

Fig. 1 Integrated delivery structures for the planning and implementation of carbon-neutral neighborhoods (CNNs) (Source: Developed from Sustainable Development Commission 2010, p. 64)

	Buildings e.g. Improved energy efficiency of dwellings and community buildings	Local energy generation e.g. Household micro-generation & community level installations	Waste e.g. Reduce repair/reuse and recycle domestic waste	Local transport e.g. Electric car clubs, cycle-ways and walk-ways	Water efficiency e.g. Reduce domestic consumption and reuse grey water	Green infrastructure e.g. Sustainable urban drainage, allotments, green roofs, street trees
Reduce carbon emissions	●	●	●	●	●	●
Increase resilience to climate change	●	●			●	●
Reduce fuel bils & fuel poverty	●	●				
Improved energy security		●				
Increased efficiency in resource use	●	●	●	●	●	●
Improved biodiversity						●
Improved health	●			●		●
Local green jobs created	●	●	●			
Local economies strengthened	●	●				
Increased value and quality of neighbourhood	●			●		●
Reduced crime / fear of crime				●		

Fig. 2 Objectives and action opportunities for carbon-neutral neighborhoods (Source: Developed from Gibson 2007, p. 15)

multi-agency planning. However, it increasingly understood that success will need a combination of both "top-down" and "bottom-up" innovations in multi-sector working. At neighborhood level, local municipalities with their private sector and community partnerships are pioneering low carbon new housing development, neighborhood retrofitting, and community renewable energy schemes. Upscaling these "local success stories" is essential for meeting carbon reduction targets.

The headline target for mitigation is to reduce the national total of carbon emissions by 18 % on 2008 levels by 2020, as a major step toward achieving the legally binding target of cutting emissions by 30 % by 2050, which was embodied in the *Climate Change Act 2009*. The UK was the first (and is still the only country) to pass a law which imposes a legal obligation on government to achieve a specified carbon reduction target by a specific date. The *UK Low Carbon Transition Plan* (DECC 2009) is a cross-sector plan which provides the integrating framework for action by government, the private sector, and NGOs/community organizations. It was developed by the Labour government in the run-up to the 2009 Copenhagen Summit and is now being taken forward by the new center-right coalition government which has pledged itself to be "the greenest government ever." In common with other national plans, this plan emphasizes climate change mitigation focused on reducing carbon emissions especially from the built environment and transport. It aims to cut emissions from homes by 29 % on 2008 levels by 2030. Three key action programs are now underway to achieve these targets.

The first is a phased move toward zero carbon new housing and, eventually, zero carbon new communities, in order to slow down/halt the increase in energy demand from new construction. In 2006, the UK government announced that it would ramp up the environmental component of the building regulations in 2008, 2010, 2013, and finally to zero carbon in 2016, using the new Code for Sustainable Homes. The Code covers nine areas: energy, water, materials, surface water run-off and waste, pollution, health and well-being, management, and ecology. The Code Levels are 1–6. The highest standard is Level 6 – a zero carbon development emissions achieved through energy conservation and the use of renewable energy. All new social housing construction had to achieve Code Level 3 from April 2009, as a condition of government funding. Thus social housing associations and their contractors are tasked with spearheading the move toward zero carbon housing.

The second is to secure the retrofitting of existing energy-inefficient housing, through a new Energy Company Obligation (ECO), requiring energy companies to participate in the *Green Deal*. This is a "pay-as-you-save system" which came into operation in spring 2013. The capital cost of the energy efficiency measures is paid to back to "green deal providers" by users of dwelling from the reduction in their energy bills. The third program aims to increase the proportion of energy from renewable sources 4–30 % by 2020. This requires the electricity supply companies to sell electricity generated from large-scale renewable sources, including wind, solar, and nuclear. But it requires incentives and standards to dramatically increase microgeneration from renewable sources. Taken together, these measures have the potential to deliver the key component of carbon-neutral neighborhoods, by ensuring that the levels of energy efficiency of neighborhood buildings are so high that the neighborhood's microgeneration capacity can meet its minimal energy requirements.

Policy makers developing the UK national climate change action plan were able to draw on the experience of a significant number of pioneering local authorities, both at home and abroad (Allman, et al. 2004; Granberg and Elander 2007). The national plan now provides a framework within which there is the potential for this innovative work to be progressively mainstreamed. In this context, the city of ***Brighton and Hove*** has recently revised the city's climate change strategy to meet the overall objective of "living within environmental limits" (see Fig. 3; Brighton and Hove City Sustainability Partnership 2011). The city has signed up to Nottingham Declaration commitment to "develop our plans with our partners and communities to progressively address the causes and impacts of climate change." This is the main UK network of local authorities which promotes and shares good practice.

The climate change strategy is managed by Brighton and Hove City Sustainability Partnership, a multi-sector and multi-agency partnership organization, led by the city council and covering all the key sectors. Data provided by central

Fig. 3 The city of Brighton and Hove on the south coast of England; between the South Downs and the English Channel (Source: *1*. www.smoothhound.co.uk; *2*. ww3.brighton-hove.gov.uk/index.cfm?request=b1120082&node=1576; *3*. www.ordnancesurvey.co.uk/shop/explorer-map-brighton-hove.html; and *4*. www.takethefamily.com/)

government gives the city's annual CO2 emissions as 1.2 m tonnes, which is 4.8 tonnes per person. By sector, 42 % of emissions are from housing, 32 % industrial and commercial, and 26 % transport. The partnership has agreed the city's targets as its contribution to the national target: from a 2005 baseline, a 42 % reduction in emissions by 2020 and an 80 % reduction by 2050. The strategy to achieve these targets uses an approach based on five high-level outcomes to provide a clear but flexible framework. For each outcome, the strategy promotes an understanding of the issue and provides a structure for actions. The outcomes are a low carbon economy, low carbon buildings, low carbon transport, and renewable and sustainable energy. Each of these areas is led by a senior city councilor and is broken down into sub-outcomes (manageable pieces), which have an implementation plan that identifies actions needed to meet targets, and clear processes for monitoring and review, resourcing and investment, and community engagement. For example, the *Low Carbon Homes and Buildings* section of the strategy sets out the issue in terms of the fact that buildings account for 42 % of the city's carbon footprint but that this can be drastically reduced by increasing the energy efficiency of buildings and by using low and zero carbon technologies (microgeneration) and district heating and power systems. Moreover, individual citizens can contribute by adapting their behavior in relation to water and space heating and use of electric appliances. A profile of the characteristics of housing explains that different house types have different carbon footprints and opportunities for energy efficiency improvements.

The strategy then sets out what the council is doing to promote energy efficiency improvements in existing housing, taking advantage of government grants and the subsidies which energy companies have to provide under the Energy Company Obligation. At present, the program is not targeted to particular areas as the volume of action is not large enough. However, it is likely that this will change when the Green Deal comes into operation, as the volume of activity will increase to the point where a neighborhood approach will achieve scale economies, and it may be appropriate to apply the CNN model. The strategy explains how the city is promoting low carbon construction of new housing through its sustainable building design code. Its provisions have to be complied with before planning approval is given. This requires energy-efficient design which maximizes the use of passive solar gains, natural ventilation, super insulation of walls, roofs, and floors, advanced glazing systems, high-efficiency condensing boilers, energy-efficient lighting, and energy-labeled white goods. The resultant reduced energy demand is substantially met by on-site or "near-to-site" renewable wind, solar, and geothermal sources and the use of biofuels. The award-winning New England Quarter is the city's exemplar carbon-neutral neighborhood, designed to Code for Sustainable Homes Level 5 on a redeveloped brownfield site close to the railway station and bus services.

Turkey National Climate Change Action Plan (NCCAP)

During the last three decades of the twentieth century, the explosive growth of Turkish cities has been dominated by illegal development. Initially, this took the form of squatter constructed *gecekondu* neighborhoods of single-story dwellings. This was succeeded by poor-quality, steel-reinforced concrete-frame construction apartment blocks with low levels of insulation – characteristically 5–8 stories high. The recent building boom has been dominated by the construction of large peripheral estates of high-rise blocks, often built on public sector-owned greenfield sites, creating vast car-dependent suburbs. Overall, these carbon-intensive processes have been the antithesis of sustainable urban development as demonstrated by the illustrative outcomes in Table 1.

However, another major outcome of this very rapid but weakly regulated urbanization process is that vast numbers of the poor-quality apartments were built on earthquake-vulnerable land. The deaths of more than 18,000 people in the 1999 Marmara earthquake brought an end to "earthquake amnesia" and tragically demonstrated the need for a major, earthquake mitigation-led neighborhood regeneration program.

The future of Turkish cities will be significantly shaped by the response to the dual challenge of carbon-intensive urban development and earthquake-vulnerable neighborhoods. In July 2011, the Turkish government published the National Climate Change Action Plan 2011–2023 (Republic of Turkey 2011). This plan includes a landmark commitment to reduce carbon emissions from Turkish cities. It was the culmination of a national-level policy development process that was

Table 1 Carbon-intensive Turkish urbanization

The building sector accounts for 36 % of energy consumption and 32 % of the total energy-related CO2 emissions, and on a "business-as-usual scenario," these emissions will double by 2020
Many of Turkey's new buildings (built post-2000) are energy inefficient compared with new buildings in the EU countries which have similar degree-days
Comparisons of Turkey's new buildings alongside EU countries' energy use standards reveals that even building regulation-compliant buildings require at least 50 % more energy for heating than their EU counterparts
Only 20–30 % of new buildings comply fully with the building and other regulations
There are huge opportunities for reducing CO_2 emissions by 30–50 % of current levels, including enormous scope for low-cost improvement in energy efficiency
Only 16 % of buildings have roof insulation
The use of insulation materials per person is one-tenth of the average use per person in the EU

Source: Adapted from Kocabas (2012)

structured by supranational policy drivers. Kocabas (2012) has identified the key stages in this process. In common with many other countries, the energy sector was the first to incorporate a climate change dimension. The EU harmonization process included a major technical assistance project that provided the basis for new legislation to increase building regulation minimum energy standards and incentivize increased investment in renewable energy sources through a feed-in tariff.

The implementation of the EU's Building Energy Performance Directive in 2011 made the energy efficiency levels of all new buildings transparent by introducing energy identity documents (EIDs). Moreover, by 2017, all existing buildings will require EIDs which will specify how energy efficiency can be improved. The EU harmonization processes also positively influenced the Turkish government's decision to sign the Kyoto Treaty in February 2009. In turn, this gave impetus to the implementation of legislation to enable the government to adopt the target of moving toward 30 % of total energy production from renewable sources by 2023. In parallel, a UNDP-funded research and development project demonstrated the enormity of the challenge of reducing the negative impact of the building stock on levels of carbon emissions.

The Turkish National Climate Change Action Plan (NCCAP) was a result of international collaboration between the UNDP, the British Foreign and Commonwealth Office, and the Turkish government. For each sector, the plan sets out objectives and (at this stage) modest targets for short, medium, and long terms, together with the responsible organizations in public, private, and NGO sectors. The targets for the energy and buildings sectors establish new parameters for Turkish urbanization and are summarized in Table 2.

They constitute a commitment to move toward climate-sensitive physical development planning, as part of a wider process of climate change mitigation. This overall approach is recognizably similar to that adopted by other governments, as is the expectation of a significant role for local municipalities in the further development and implementation of the national strategy.

Table 2 The NCCAP's new parameters for Turkish urban development

Buildings and energy
Increasing energy efficiency in commercial and public buildings over 10 k sq m floor
Increasing energy efficiency in at least one million (out of a national total of 8.5 million) residential buildings by 2023
Developing financial incentives for energy efficiency and renewable energy by the end of 2013
Decreasing energy consumption in public buildings by 10 % by 2015 and 20 % by 2023
At least 20 % of energy in new buildings to be from renewable sources by 2017, including on-site microgeneration in major housing developments
Settlements and carbon emissions
Reducing carbon emissions in new pilot project settlements by 10 % by 2015
Reducing carbon emissions from all new settlements by 10 % by 2023

Source: Adapted from Kocabas (2012) and Republic of Turkey Ministry of Environment and Urbanisation (2011)

> In order to combat climate change more effectively... it is very important for the local administrations to integrate the issue of climate change into their own strategic plans and programmes and to prepare Local Climate Change Action Plans. (Ministry of Environment and Urbanisation 2011, p. 2)

This proposal that local authorities should integrate climate change into their strategic plans and programs, in the context of an overarching climate change strategy, is consistent with the general approach which continues to evolve in EU countries, as discussed above. However, it has emerged at a time when there is about to be a major development of new strategic plans and programs for earthquake-led neighborhood regeneration. After more than a decade of debate and pilot studies, the new Ministry of Urbanisation and Environment (2011) now also have responsibility for implementing new urban regeneration legislation (Law no: 6306, May 2012). This is an important milestone on the road to the major and long-term demolition and rebuilding program that is needed to avoid a humanitarian disaster in the next earthquake. But a major neighborhood regeneration program is also an opportunity to significantly reduce carbon emissions from housing in Turkish cities, by replacing energy-inefficient housing with carbon-neutral neighborhoods.

Local Climate Change Action Plans: Prospects for Kartal

The policy makers developing the UK national climate change action plan were able to draw on the experience of a significant number of pioneering local authorities to produce a national plan which now provides an integrated framework within which there is the potential for this innovative work to be progressively mainstreamed. The Turkish national plan was published only 2 years later, but in sharp contrast, it emerged from a context in which no local authority had established a climate change action plan and the limited "bottom-up" experience was restricted to the environmental projects of a few municipalities together with

NGO campaigns and associated small-scale exemplar projects. In the context of the review of UK experience, the prospects of local municipalities developing a significant role de novo will now be assessed with reference to the Kartal municipality (see Fig. 4).

The Regional Environment Center (REC) is the leading NGO in the field. Within a few months of the publication of the NCCAP, REC jointly organized a conference with the French Development Agency (AFD) entitled “Sustainable Cities in Turkey.” This initiative was designed to focus attention on the question of how to manage the transition to a low carbon era. The mayor of Kartal, Dr. Oz, was a keynote speaker. His election manifesto had the stated aim of moving Kartal toward becoming a “sustainable ecological town,” which was shared with the public and council employees through subsequent vision and mission statements. He outlined some of the results of the work that Kartal had been undertaking over the previous 2 years, which are summarized in Table 3.

He argued that all municipalities should develop action plans but warned that generating public support would be very challenging as “the public are not ready yet,” illustrating his point by reference to the difficulties of improving domestic waste recycling rates. At the strategic level, he drew attention to the potential of the municipality working in partnership with the Greater Istanbul Metropolitan municipality to realize the potential of urban regeneration for saving energy and saving water. Such a partnership could draw Kocabas’ (2010) scenario for sustainable urban regeneration. EU experience has shown that international and intranational networking is an important element in the dynamic of developing local climate change action plans.

Kartal is one of the few Turkish municipalities which are a participating member of the International Council for Local Environmental Initiatives (ICLEI), and the mayor stressed the value of international networking in supporting the development of local initiatives. Importantly, the conference signified the beginning of intranational networking between Turkish local municipalities. In a move which echoed the Nottingham Declaration in England and similar initiatives in other EU countries, municipalities were given the opportunity to join a website which would be developed as a forum for sharing experience and promoting good practice. Thus, Kartal is in a good position to build on its portfolio of environmental projects to develop a local climate change strategy and action plan, within the new national climate change action framework and new urban regeneration laws.

Drawing on the contemporary experience of EU cities, illustrated by Brighton, this process could include:

- Carrying out an audit and evaluation of recent and ongoing local environmental projects to assess potential for development and replication
- Creating a Kartal Environmental Partnership to facilitate coordinated interagency working
- Establishing a municipality carbon emission baseline, such as that recently completed in the nearby municipality of Kadıkoy, as a basis for monitoring and evaluating the impact of local action

Fig. 4 Kartal District Municipality on the Anatolian side of the Bosphorus; between the Aydos Hills and the Sea of Marmara (Source: *1*.www.avrasyanakliyat.com; *2*. www.webrehberi.net; *3*. www.panoramio.com; *4*. http://upload.wikimedia.org/ and *5*. www.emlakwebtv.com)

Table 3 Environmental initiatives in Kartal district

Leading by example: The municipality is converting a multistory car park into a green municipal building to provide accommodation for council departments which will replace an earthquake-vulnerable building which will be demolished
Lighting public parks: Eight public parks in Kartal are now lit by renewable energy from photovoltaic panels installed in the park, reducing emissions and providing a symbol of the council's intent
Improving water management: The municipality construction directorate now requires all residential developments to include facilities for rainwater harvesting which can be used for gardens rather than periodically flooding the streets; automated irrigation systems for parks and gardens have replaced tankers, reducing both operation costs and carbon emissions
Local sourcing of sustainable organic food: The municipality has established the first 100 % organic market on the Anatolian side of Istanbul and is promoting organic farming in the Aydos Hills which run parallel to the coast

Source: Authors' research

- Setting targets for carbon emission reductions from the municipal area
- Systematically identifying ways in which sector plans and projects could contribute to meeting carbon reduction targets, particularly by building on recent initiatives, e.g., further carbon reductions from public buildings
- A Kartal code of sustainable construction to be used to incrementally increase building standards, in both new neighborhoods and neighborhood regeneration areas
- A local energy policy to promote domestic energy efficiency and the enhanced use of renewable energy in existing homes
- A food strategy to enhance local access to healthy food
- A systematic capacity-building program for public, private, and NGO sectors

Conclusion

Planning for low carbon cities in Turkey has now started. Overall, the current state of local climate change action in Turkey is evocative of the experience of that in EU cities in the early 2000s. However, the key difference is that initial experience in Turkey will develop within the framework of an approved national climate change action plan which provides a basic policy framework and incentives for local action. Moreover, the government is now recognizing the potential of developing local climate change action plans and local urban regeneration programs in tandem. These conditions enhance the prospects of the more enterprising municipalities developing climate change action plans relatively quickly. However, national government has yet to allocate significant additional resources to incentivize municipalities, so at this early stage, much will depend on local initiative. This will require substantial capacity building, and this chapter has shown that just as international collaboration has had a positive influence at national level, so it is now appropriate for Turkish municipalities, like Kartal, to systematically draw on the experience of contemporary local climate change action plans from cities like Brighton.

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Climate Change: Safeguarding Indigenous Peoples through "Land Sensitive" Adaptation Policy in Africa

Ademola Oluborode Jegede

Contents

Abstract

While, generally, climate change affects Africa negatively, indigenous peoples will suffer more, considering their lifestyle which is intricately attached to land. On three grounds, this chapter argues the importance of safeguarding indigenous peoples through "land-sensitive" adaptation policy at the national level in Africa. First, this is based on the evidence of existing forms of "land-sensitive"

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adaptation practices among indigenous peoples in the face of climate variability over time in Africa. Second, the current emerging range of climatic variation in Africa, however, challenges these "land-sensitive" adaptation practices of indigenous peoples. Finally, although international climate adaptation policy requires the protection of indigenous peoples in its processes, states in Africa hardly comply with this prescription while engaging with these processes at the domestic level. The chapter concludes by suggesting what a "land-sensitive" adaptation policy at national level should embody for indigenous peoples in Africa.

Keywords

Africa • Climate change • Adaptation policy • Adaptation practices • Indigenous peoples' land use and tenure

Introduction

The contributions of Working Group 1 to the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) in 1990 (Watson et al. 1990), 1995 (Houghton et al. 1995), 2001 (Baede et al. 2001), 2007 (Le Treut et al. 2007), and 2013 (Stocker et al. 2013) have overwhelmingly explained the scientific and factual basis of climate change. According to these contributions, human activities are substantially increasing the concentration of greenhouse gases in the atmosphere, thus enhancing greenhouse effect, which has in turn led to increased warming of the earth's surface resulting in climate change (Le Treut et al. 2007; Baede et al. 2001; Houghton et al. 1995; Watson et al. 1990). With an economy largely agrarian and limited adaptation capacity, populations in Africa are and will be seriously affected by climate change (Toulmin 2009; Wold et al. 2009, pp. 1–47; Collier et al. 2008, p. 337; Boko et al. 2007). Although, there is no Africa-wide climate homogenous effect (Collier et al. 2008, p. 338), in general terms, climate change's negative impacts for Africa, actual and projected, is expected on areas such as water resources, food security, natural resource management and biodiversity, human health, settlements and infrastructure, and desertification (Toulmin 2009, pp. 15–87; Boko et al. 2007, pp. 10.2–10.6).

Even though indigenous peoples have contributed least to climate change, according to the United Nations Development Group's Guidelines on Indigenous Peoples' Issues (UNGGIPI 2008, p. 8), "they are the first to face its impact." Indeed, indigenous peoples will be disproportionately affected by climate change (Crippa 2013, p. 124; UNHRC 2009 Resolution 10/4; Salick and Byg 2007, p. 4; Stern 2006, p. 95). Through a review of literature, using a descriptive and analytical approach, this chapter contends that safeguarding indigenous peoples through "land-sensitive" adaptation policy is important at the national level in Africa for three reasons. First, there are existing forms of "land-sensitive" adaptation practices among indigenous peoples in Africa based on their experience of climate variability. Second, given the emerging range of climatic variation in Africa, these "land-sensitive" adaptation practices of indigenous peoples are under threat.

Finally, despite the requirement in international climate adaptation policy for the protection of indigenous peoples in its processes, states in Africa do not specifically attend to the adaptive concerns and practices of indigenous peoples while engaging with international adaptation policy requirement.

Understanding Terms: "Indigenous Peoples" in Africa, "Land-Sensitive" and "Adaptation"

In the interest of clarity, there are key terms which are employed in this chapter that merit brief explanation.

"Indigenous Peoples" in Africa

Although the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) was adopted in 2007 with the participation of states in Africa, the concept of indigenous peoples is disputed in Africa (Viljoen 2012, p. 230; Ndahinda 2011, pp. 1–13; Bojosi 2010; ACHPR and IWGIA 2005). The argument questioning their status stems from the difference in historical encounter with colonialism which, unlike in the Americas and Australasia, did not come with significant displacement of any population in Africa. In those parts of the world, the concept of indigenous peoples is understood as describing the identity of people who were the first to settle on the land from which they were displaced by European colonizers (Anaya 2010, pp. 23–42). In this context of displacement by colonialism, political leadership in Africa has generally argued that every "African is indigenous to Africa" (Viljoen 2012, p. 230; Barume 2010, p. 20; ACHPR and IWGIA 2005, pp. 86–89). However, this position, as it has been validly argued, ignores the situations of hunters and gatherers as well as pastoralists whose peculiar nature of land tenure and use had been disrupted due to internal suppression by dominant groups which existed in pre-colonial Africa and thereafter (ACHPR and IWGIA 2005, p. 92).

Hence, scholarly writings, including Kidd and Kenrick (2009, pp. 8–9) and Wachira (2010, p. 313), and indeed the regional commissioned reports such as the Report of the African Commission's Working Group of Experts on Indigenous Populations/Communities (ACHPR and IWGIA 2005) and the Advisory Opinion of the African Commission on Human and Peoples' Rights on the United Nations Declaration on the Rights of Indigenous Peoples (AU and ACHPR 2007), recognize the presence of indigenous peoples in Africa. According to the ACHPR and IWGIA (2005), the report of the Working Group prescribes the criteria for identifying indigenous peoples/populations in Africa and argues that the African Charter on Human and Peoples' Rights (African Charter) protects their collective rights. These are, namely, (1) the occupation and use of a specific land; (2) voluntary perpetuation of cultural distinctiveness; (3) self-identification, as well as recognition by other groups, as a distinct collectivity; and (4) an experience of subjugation, marginalization, dispossession, exclusion, or discrimination (ACHPR and IWGIA 2005, p. 93).

While there is no requirement that all the four elements should be present for a given population to constitute indigenous peoples in Africa (ACHPR and IWGIA 2005, p. 93), the literature has stressed the importance of these criteria. Kidd and Kenrick (2009), Wachira (2010, p. 313), and ACHPR and IWGIA (2005, p. 93) emphasize the peculiar cultural lifestyle of indigenous peoples which is evidenced in a number of ways including language, social organization, religion and spiritual values, modes of production, laws, and institutions. Also, the writings of Daes (2011, p. 465, 2010, p. 18) and Anaya (2010, pp. 23–42) identify self-identification, marginalization, and collective cultural and physical dependence on land as some of the markers of their identity. More importantly, the report of the Working Group offers extensive examples of these groups in Africa, noting however that the list is not exhaustive (ACHPR and IWGIA 2005, pp. 15–19). According to the report of the Working Group, those whose lifestyle defines these criteria in Africa are the hunters and gatherers as well as the pastoralists (ACHPR and IWGIA 2005, pp. 14–61).

"Land-Sensitive"

Generally, considered from the lens of "indigenous peoples' knowledge" or "indigenous peoples' land ethics," the worldview of indigenous peoples toward the environment has been robustly debated (Raygorodetsky 2013; CHARAPA et al. 2012; Desmet 2011; Heinämäki 2010; Nelson 2010; Jaska 2006; Berkes et al. 2005; Johannes 2002; O'Connor 1994; Tsosie 1996; Asiemat and Situmatt 1994; Durning 1992; Doubleday 1989). Particularly, in the context of climate change, the centrality of indigenous knowledge about their environment as a resource for adaptation has been well explored in climate-related literature (Raygorodetsky 2013; Burket and Davidson 2012; Macchi et al. 2008; Salick and Byg 2007). However, while this approach is useful, it should be embraced with caution in discussing climate change impacts on indigenous peoples in Africa. The exercise of caution is necessary because such an approach can potentially obscure the reality that adaptive challenges and practices of indigenous peoples are not isolated but dependent on a unique attachment to land. Also, while the focus on indigenous peoples' knowledge may be helpful in addressing the scourge of climate change, this may be overrated and counterproductive. This is in the sense that the focus on indigenous peoples' knowledge by policy makers may divert attention from the urgent need to address more fundamental issues such as land tenure and access that are central to the strengthening of indigenous peoples' adaptive practices.

Additionally, the land of indigenous peoples forms part of their worldview and so they are culturally dependent on the land (Asiemat and Situmatt 1994, p. 151). Hence, any change within the environment of indigenous peoples is best discussed in the context of changes "to and in the community's right to land" (Asiemat and Situmatt 1994, p. 159). More importantly, a focus on land is crucial considering that the UNDRIP holds land as central in the protection of indigenous peoples (UNDRIP 2007, arts 25 and 26). Accordingly, "land-sensitive" connotes an adaptation policy approach that includes respects and enhances the land use and tenure of indigenous peoples in the light of climate change challenge in Africa.

Adaptation

Adaptation has been a central part of international climate negotiation. Initially, it was thought of as a "taboo" to discuss adaptation in the climate change negotiation as advocates for climate mitigation feared that politicians were likely to lose interest in mitigation if adaptation options become the focus of discussion (Pielke et al. 2007, p. 598). However, for developing states and vulnerable populations, it has been argued that it will amount to playacting to imagine that adaptation is not urgent (Burney et al. 2013, p. 52).

Adaptation is understood as measures that can be used in coping with the "ill-effects of climate change" (Caney 2009, p. 203) or activities geared toward the prevention of impacts of climate change from being harmful (Paavola and Adger 2006, pp. 594–609). The IPCC defines adaptation as an alteration in the natural or human systems in response to actual or expected impacts of climate change with the aim of moderating the harm in climate change or exploiting its beneficial opportunities (Watson et al. 1990, p. 398). Adaptation also connotes the adjustments to reduce vulnerability or improve flexibility to the observed or expected changes in climate, involving a range of options such as processes, perceptions, practices, and functions (Boko et al. 2007).

The potentials and options for adapting to climate change at the domestic and regional levels have been given considerable attention in climate change literature. Adaptation, explains Goklany (2005, p. 675), can take advantage of positive impacts and reduce negative impacts of climate change. According to Solomon et al. (2009, p. 1708), some impacts of climate change, such as sea level rise, can be addressed by constructing sea walls. Also, as it has been generally shown, in some regions, an appropriate adaptive strategy might entail swapping from negatively impacted products to less impacted crops (Lobell et al. 2008, p. 610) or the use of new crop varieties and livestock species better suited for drier conditions, as well as the use of irrigation, crop diversification, adoption of mixed-crop and livestock farming systems, and alternating planting dates (Kurukulasuriya and Mendelsohn 2008, p. 6; Nhemachena and Hassan 2007).

Having described the key concepts used in this chapter, three arguments proposed in favor of safeguarding indigenous peoples through "land-sensitive" adaptation policy in Africa are discussed in the next sections.

Indigenous Peoples' Existing "Land-Sensitive" Adaptive Practices

From the outset, it should be stated that there are arguments suggesting that indigenous peoples' relationship with land is not harmonious or any different from the approach by mainstream society. For instance, Lüdert (2009, pp. 7, 20), citing the economic benefits derived by the Bayei in Northern Botswana from ecotourism projects in their territory, is of the view that indigenous peoples are involved in the commodification of nature. Also, attempting to show that the relationship of indigenous peoples' with their land is not necessarily harmonious, The Economist (2012) and D'Amato and Chopra (1991) note that the activities of the Inuit, indigenous peoples of arctic Canada, Alaska, Greenland, and Siberia, are injurious to whales and should not be exempted if an international norm should emerge granting the whale a right to life. Maragia (2006, p. 219), Berkes et al. (2005, p. 1252), and Tsosie (1996, p. 268) equally demonstrate that not all traditional perception of the indigenous peoples in relation to their land is ecologically adaptive. According to Neely et al. (2009, pp. 9–10), herding of cattle may result in overgrazing and, in effect, land degradation, a major factor in climate change. As explained by Adeloye and Okukpe (2011, p. 56), the manure of herds, except if properly handled, is a major source of greenhouse gas emission which brings about global warming.

However, the validity of these arguments is disputed. Although the activities of indigenous peoples may negatively impact their land, this is only minimal. More than any other populations, the indigenous peoples have reasons to be friendly with their land. Foremost, and according to West and Brockington (2006, pp. 609–616), indigenous peoples view their land as a divine gift or heritage and themselves as its guardian or protectors. Having lived in this land for long, indigenous peoples hold their land in great respect (Woodliffe 1996, p. 256, Durning 1992, p. 112). Sensitivity to land is evidenced in the understanding that land is significant for their cultural preservation (Woodliffe 1996; Cohen 1993, p. 195). The land of indigenous peoples is a site of several items they hold dear to culture and spirituality such as sacred mountains, rivers, lakes, caves, single trees or forest groves, and coastal waters (McLean 2010). As Anaya (2000, p. 2) observes, indigenous peoples living in forested areas consider the survival of the forest as essential to the survival of human life.

This is in fact generally the case with indigenous peoples in Africa. Among the San peoples of the Kalahari in Southern Africa, according to Lee (2000), land represents a "sense of place" and the means through which they display a sense of harmony with nature. The San peoples, as Chennells (2003, pp. 278–279) reports, "know what to do with the land" and "every plant, beetle, animal" in the Kalahari. Generally, the protection of the indigenous peoples' land and its biological communities are therefore viewed as a prerequisite for survival (Suagee 1999, pp. 48–50). Findings also show that among the Mbendjele (pygmies) of Congo-Brazzaville, forests fulfill the cultural role including serving as places where pregnant women give birth to children, for finding indigenous foods, and for sharing stories relating to traditional practices such as "past hunting, fishing, or gathering trips" and eternal abode after death (Lewis 2001, p. 7). According to Asiemat and Situmatt (1994, p. 149), the Maasai of eastern Africa, particularly Kenya, conceive land as an important host not only of themselves as a people but of the plants, animals, trees, and fish which, among other things, all constitute their cultural and environmental universe.

It is the foregoing worldview about land that supports several forms of adaptive practices among indigenous peoples in different parts of Africa in the face of adverse impacts of climate change over time. While these adaptive practices vary, a common trend is that these practices portray indigenous peoples' resilient adjustment to the use of land, despite the harsh reality of climate change. This pattern of adjustment, as it is illustrated in the next section, cuts across different scenarios of climate impacts including prediction of weather, water scarcity, drought, land degradation, and food insecurity.

Prediction of Weather

Indigenous peoples in Africa have devised diverse means of predicting the weather. Environmental conditions, such as rainfall, thunderstorms, windstorms, and dusty winds, have been reportedly used by indigenous peoples in preparing for future use of land and weather forecast in West Africa (Ajani et al. 2013; Ajibade and Shokemi 2003). More particularly, the Maasai in the eastern part of Africa do predict droughts by observing the movement of celestial bodies and combining such with watching the development of certain plants. This has been reported as useful in serving as an early warning signal of an approaching environmental disaster as well as an early indication of "the condition of the range of land and its likely changes" (UNFCCC Adaptation Case Study 2013a). Other forecasting approaches, according to Roncoli et al. (2001), include the timing of fruiting by certain local trees, the water level in streams and ponds, the nesting behavior of small quail-like birds, and the insect behavior in rubbish heaps outside compound walls.

The foregoing has adaptive utility. Outcome of weather prediction enables indigenous peoples in Kenya to understand storm routes and wind patterns and, hence, to design local disaster management practices in advance. This is achieved by constructing appropriate shelters, windbreak structures, walls, and homestead fences (UNU-IAS-TKI 2009, p. 55). Also, as a result of prediction of weather, indigenous peoples are able to plan daily economic life and social activities with foresight. This possibility further results in adaptive strategy such as planting appropriate crops that suit a particular season (UNU-IAS-TKI 2009, p. 55). Generally in East Africa, knowledge about weather condition enables the pastoral Maasai to prepare for drought and make decisions about where to graze and which grasses recover faster than others (UNU-IAS-TKI 2009, p. 55).

Water Scarcity Coping Approach

A range of adaptive measures is also being taken by indigenous peoples in conditions of scarcity of water. The Maasai accurately assess the water-holding capacity of distant pastures to plan transhumance activities. Generally, pastoral communities living in the water-deficient areas engage in rainwater harvesting which is conserved for all their needs. Other approaches include the construction of "sand dams" which slows down flash floods and holds the water in the sand of the riverbed (UNFCCC Adaptation Case Study 2013b). Shallow wells may also be provided with sanitary seals to protect them from contamination and unnecessary siltation after floods. This, in essence, helps in reducing the caving in of wells during the floods thus making water available for a longer period and reducing human stress (UNFCCC Adaptation Case Study 2013b).

Drought and Land Degradation Management Skills

Among the Tuaregs in North Africa as well as in the south of the Sahara, adaptive practices of coping with drought and land degradation have been documented. “Fixation sites” are constructed since 1990 to assist in coping with spread of desertification (Woodke 2007, pp. 10–11; Harris 2007). Also, during drought periods, the pastoralists in this region change from cattle to sheep and goat husbandry (Seo and Mendelsohn 2006) or move from the dry northern areas to the wetter southern areas of the Sahel (McLean 2010, p. 60). Additionally, the Sukuma people of the north of Tanzania engage in soil conservation through which animal fodders are prepared and made available to very young, old, or sick animals unable to follow other animals to grazing lands. The process encourages the conservation of grazing and fodder lands by encouraging vegetation regeneration and tree planting (UNFCCC Adaptation Case Study 2013c).

Food Preservation

To cope with loss of crops and food insecurity, fodder is of huge importance to nomadic people whose livestock is often the only source of income. Among the Tuaregs, there is evidence of enclosures designed to protect and safeguard pastures (Woodke 2007). Preservation of items such as fruits, vegetables, and edible insects is demonstrated in two ways: for vegetables, it is usually to immerse the fresh vegetables in salty boiling water and spread for drying after boiling for a few minutes to avoid loss of nutrient, and for drying caterpillars, termites, white ants, and other edible insects, this may be directly spread in the sun (UNFCCC Adaptation Case Study 2013d). The practice of sun drying among indigenous peoples is a coping mechanism found in several states in Africa including Ethiopia, Kenya, Niger, Tanzania, Senegal, and Democratic Republic of the Congo (FAO 1985).

Notwithstanding these existing forms of adaptation among indigenous peoples, the “land-sensitive” adaptation practices of indigenous peoples in Africa are threatened by a new emerging range of climatic variations requiring urgent policy attention by states in Africa.

Increasing Climate Variation as a Threat

Climate variation is increasing with peculiar adverse impacts on indigenous peoples’ land in different regions of Africa (IPACC Web; IWGIA 2011; Mclean 2010; Tebtebba 2010). This arguably threatens the existing adaptive capacity of indigenous peoples in Africa. Although the experiences of indigenous peoples throughout Africa are not the same, they share common experience of vulnerability to climate change, notwithstanding adaptive practices.

According to the ACHPR and IWGIA (2005, p. 18), among indigenous peoples in West Africa are the Baka, Mbororo, and Tuareg. In the territories of these groups, there is reported evidence that the consequence of climate change is typified by destruction of grazing lands, drought, reduced access to safe water, and destruction of plants and animals (IPACC Web; Mclean 2010, p. 42; Woodke 2007, pp. 10–11). In East Africa, there are several indigenous peoples' groups, among which are the Maasai, Ogiek, Endorois, and Yaaku in Kenya (CHARAPA et al. 2012, pp. 29–39; Tebtebba Foundation 2010, p. 440). These peoples experience several negative conditions as a result of a changing climate, including land degradation, drought, flood, famine, and displacement (UNFCCC 2013; CHARAPA et al. 2012, pp. 35–37; IWGIA 2011, p. 410).

The Batwas in Rwanda, Burundi, Uganda, and Democratic Republic of the Congo (DRC), also known as Baka in Central African Republic (CAR) and Gabon, Baka, and Bagyeli in Cameroon, are in the Central Africa and Great Lakes region (ACHPR and IWGIA 2005, p. 16). The recent experiences of these peoples include a lengthy dry season and unpredictable weather conditions, which are affecting the agricultural calendar and bringing scarcity of forest products such as fruits and tubers, thereby disturbing their cultural lifestyle (Baka People Video 2013; Tebtebba 2010, p. 481; Mclean 2010, p. 44; CWE 2009, p. 2). More frequently, to the Mbororo and other pastoralists in the same region, transhumance calendars are being altered from January to late October due to a shift in the start of the dry season (Tebtebba 2010, p. 481; Mclean 2010, p. 44).

In the north of Africa are indigenous peoples known as the Amazigh (or Imazighen), also referred to as the Berbers or Tuaregs (ACHPR and IWGIA 2005, pp. 18–19). Evidence of climate impacts on their land includes scarcity of water, degradation, desertification, overgrazing, and salinization, in a changing climate (McLean 2010, p. 42; IISD 2001). In the southern part of Africa, the San, or Basarwa, peoples of the Kalahari (ACHPR and IWGIA 2005, p. 17) face increasing dune expansion and increased wind speeds which have resulted in a loss of vegetation and negatively impacted traditional cattle and goat farming practices (UNPFII 2008). In the Horn of Africa, the Doko, Ezo, Zozo, and Daro Malo in the Gamo Highlands experience increasing pressures on local resources and great hardship through increase in temperature, scarcity of water, dying animals, and fewer grazing land (Gamo Video Report 2013). The “Outsa” leaf which is used for shelter, animal grazing, and food and hence crucial to the survival of these peoples is fast disappearing (Gamo Video Report 2013). The situation is not different with the Afar people to the northeast of Ethiopia. Living in an extremely fragile environment worsened by climate change, the Afar suffer damage of flash flooding, change in river courses, increased desertification, herd loss, hunger, thirst, and famine (Gardo 2008).

In sum, across Africa, the foregoing emerging and increasing impacts of climate change are overwhelming and beyond the capability of existing adaptive measures being used by indigenous peoples in the face of droughts, flooding, famine, and loss of grazing land and livestock. This is largely because increasing variations of climate impact disrupt the land use and result into displacement of indigenous peoples from the land which is crucial to their adaptive practices.

Generally, land degradation reduces the availability of ecosystem goods to these populations for adaptation purposes (Nkem et al. 2010; Tobey et al. 2010). More specifically, insecurity of land tenure and use has been found to constrain adaptation practices among indigenous peoples in states including Mali (Ebi et al. 2011) and Uganda (Hisali et al. 2011) and generally in the Congo Basin region (Nkem et al. 2010). Even where partial communal tenure is recognized as in Kenya, Namibia, and DRC, discrimination against traditional land use and livelihood strategies, logging concessions, commercial farms, and large-scale development projects (dams, oil exploitation, floriculture) are major constraint to local adaptation practices (CHARAPA et al. 2012, p. 87). Insecurity of land tenure and use and the resultant changing livelihood are a driver of declining traditional relationship with the land, a major source of adaptation information and knowledge (Pearce et al. 2011, 16.3.2.1; CHARAPA et al. 2012, p. 88).

Besides, the emerging range of climate variation requires long-term adaptation strategies, which the existing adaptive practices of indigenous peoples cannot achieve on their own without nontraditional technology and resources as complements (CHARAPA et al. 2012, p. 87). The nontraditional measures refer to the transfer of modern technology and resources that most indigenous peoples do not possess. The need for technology and resources cannot be overemphasized considering that indigenous populations live in remote places of a country, characterized by poor infrastructure, limited basic services, and poor government presence (Macchi et al. 2008, pp. 49–50). Technology can help in complementing or improving existing adaptive strategies linked with their land in coping with increasing impacts of climate change resulting from the emerging range of climate variation (Fleischer et al. 2011). Also, availability of funds is a good resource that may improve traditional or indigenous adaptation practices (Peters et al. 2013, p. 16.6; Nakhooda et al. 2011, p. 7).

Yet, while the existing climate variability challenges the adaptive capacities of indigenous peoples, the approach by states in Africa to this reality does not show an effective implementation of international processes for adaptation measures in such manner that addresses the adaptive challenges of indigenous peoples.

Weak States' Role in Engaging Adaptive Processes

Although the pillar instruments of climate change at the international level, the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and a range of decisions by the Conference of the Parties (COP) and Meeting of the Parties (MOP) under the Kyoto Protocol, require states to follow certain processes in responding to adaptation concerns, indigenous peoples' adaptive concerns and capacities are hardly specifically addressed in the framing of adaptive challenges by states in Africa.

International Climate Change Adaptation Processes

The pillar instruments of the climate change, the UNFCCC, the Kyoto Protocol, and a range of decisions by the COP under the UNFCCC and the MOP under the Kyoto Protocol, set out the standard processes for international adaptation measures. Article 4 (1) (b) of the UNFCCC enjoins all parties to "formulate, implement, publish and regularly update national. . .programmes containing measures to facilitate adequate adaptation to climate change. . .." Also, article 4 (1) (e) requires parties to the UNFCCC to cooperate "in preparing for adaptation to the impacts of climate change" as well as plan for "coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods." Under the Kyoto Protocol, it is similarly evident that the national level has the directing policy role to play in documenting and implementing adaptation measures. Article 10 (b) (ii) of the Kyoto Protocol enjoins parties to "include in their national communications as appropriate, information on programmes which contain measures. . ." which may be helpful in "addressing climate change and its adverse impacts, including. . .adaptation measures."

In the decisions of the COP or the MOP under the Kyoto Protocol, there is equally a requirement on the state government for the facilitation of adaptation process. This began to feature prominently since the COP 7 held in 2001, which acknowledged the specific needs and concerns of developing countries, including the least developing countries (LDC), and emphasized the unique role of states in addressing adaptation issues. It insisted that adaptation actions should follow a review process based on national communications and/or other relevant information (Decision 5/CP.7/2001, p. 2). It was equally stressed that support be given to the states in the preparation of the national adaptation programmes of action (NAPAs) (Decision 5/CP.7/2001, p. 15). Furthermore, the decision acknowledges the importance of indigenous resources and urges parties to take these resources into consideration as part of options for addressing the impacts of climate change (Decision 5/CP.72002, p. 24). It also formulates guidelines to facilitate preparation for NAPA (Decision 28/CP.7/2001).

The NAPA guidelines in its paragraphs 6 (a) and (c) affirm that it will be "action oriented." Paragraph 7 (f) of the NAPA guidelines reiterates that it is "a country-driven approach." While no specific mention is made of indigenous peoples, in paragraph 7 (a), it is pointed out that NAPA is "a participatory process involving stakeholders, particularly local communities," while paragraph 7 (j) assures that the process will ensure "flexibility of procedures based on individual country circumstances." The use of the term "local populations" arguably involves the indigenous peoples particularly when it is read together with paragraphs 16 (a), (f), and (h) which, respectively, require "loss of life and livelihood," "cultural heritage," and "land use management and forestry" as part of the criteria for prioritizing adaptation activities at the national level. These required items are core issues to the adaptive practices of indigenous peoples in Africa. Guidelines in relation to national adaptation plan of action were subsequently endorsed at COP 8 (Decision 9/CP.8/2002, p. 1), COP 9 (Decision 8/CP.9/2003, p. 1), and COP 10

(Decision 1/CP.10/2004, p. 4), for the developing countries in the LDC and non-LDC to document their adaptive concerns and need for funds.

Furthermore, the COP 12 in Nairobi indicates that activities to be funded under climate funds may consider national communications or national adaptation programs of action and other relevant information from the applicant party (Decision 1/CP.12/2006). At COP 13 held at Bali, an “enhanced action on adaptation” was conceived as consisting of elements including international cooperation in order to support developing states in their vulnerability assessment and integration of actions into “national planning, specific projects and programmes” (Decision 1/CP.13/2007). This was also reinforced at the Cancun meeting of COP 16 (Decision 1/CP.16/2010, pp. 11–14) which highlighted the human rights implications for adverse impacts of climate change and the need to engage with stakeholders including indigenous peoples when developing and implementing their national action plans (Decision 1/CP.16/2010, p. 12).

At a subsequent meeting in Durban, parties were urged to include in their national communications and other channels the steps they have taken in actualizing NAPA (Decision 5/CP.17/2011, p. 33), as well as indigenous and traditional knowledge and practices in adaptation strategies (Decision 6/CP.172011, p. 4). These requirements are also evident in the key decisions dealing with the access of the state to adaptation funds (Decision 28/CP.7/2001, p. 4; Decision 8/CP.5/1999). Different categories of funds in relation to adaptation are mainly the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF) established at COP 7, respectively, under Decisions 5/CP.7/2001 (p. 12) and 7/CP.7/2001 (p. 6) and Decision 7/CP.7/2001 (p. 2). Adaptation Fund (AF) was established pursuant to article 12 (8) of the Kyoto Protocol at COP 7 (Decision 10/CP.7/2001, p. 1), while a Green Climate Fund (GCF) was established pursuant to article 11 of the UNFCCC at COP16 held at Cancun (Decision 1/CP.16/2010, p. 102). The funds under the LDCF and SCCF are voluntary contributions from developed country parties to the UNFCCC (Muyungi 2013; O’Sullivan et al. 2011, p. 15) and managed by the Global Environment Facility (GEF) (Decision 7/CP.7/2001, p. 6). The GCF is managed by the GCF Board (Decision 1/CP.16/2010, p. 103), while the AF is managed by the Adaptation Fund Board (Decision 1/CMP.3/2007, p. 3). All of these funds, namely, AF (Decision 1/CMP.4/2008, p. 11), GCF (Decision 3/CP.17/2011, p. 31), LDCF, and SCCF (Xing and Fröde 2012; Bird et al. 2011), support direct access.

The guidelines relating to the operationalization of these decisions at the national level emphasize the need to safeguard indigenous peoples’ adaptive concerns and experiences in national adaptation programs. For instance, GEF Principles and Guidelines for Engagement with Indigenous Peoples set out a minimum standard relating to indigenous peoples which is expected to be complied with by partner agencies seeking to implement projects under GEF auspices in response to NAPA proposal (GEF 2012, pp. 22–29). Also the negotiation around the GCF indicates that the participation of indigenous peoples from “the local to the national to the Board level” and inclusion of their knowledge are critical to the implementation of the GCF (Martone and Rubis 2012).

Notwithstanding the foregoing, the effectiveness of the approach by states in Africa in engaging with these international adaptation processes to strengthen indigenous peoples' adaptive practices and concerns is doubtful.

Weak Approach by States

In order to comply with the requirement for adaptation funds, each of the 33 African states belonging to LDC has filed a NAPA (UNFCCC 2013b), while the developing states in Africa which are non-LDC have at least filed a national communication. The ensuing subsection demonstrates that the concerns of indigenous peoples in relation to their adaptive experiences are obscured in the official processes for capturing adaptation needs and funds. This is achieved by examining processes from Uganda, Tanzania, and Nigeria.

Uganda

The Uganda National Adaptation Programmes of Action (Uganda NAPA) was compiled in 2007. The formulation of Uganda's NAPA claims to have been guided by the principle of participatory approach and benefited from the views of the vulnerable communities and their knowledge on coping mechanisms (Uganda NAPA 2007, VII). It describes the impacts of climate change on sample districts as destruction of infrastructure, deforestation, loss of lives, famine, poverty, water shortage and drying up, erratic seasons and rains, destruction of biodiversity, and epidemics of pests and diseases (Uganda NAPA 2007, p. 27). It notes that indigenous knowledge has been employed by communities in Uganda to cope with climate events. As part of its adaptive strategies for funding, it suggests projects such as "Community Tree Growing Project" (Uganda NAPA 2007, p. 51), "Land Degradation Management" (Uganda NAPA 2007, p. 53), and "Indigenous Knowledge (IK) and Natural Resources Management Project" (Uganda NAPA 2007, p. 63).

In the document, however, impact scenarios of climate change in Uganda are discussed as though it is proportionately borne by all. It neither discloses the identity of the communities it identifies as "vulnerable" nor profiles as adaptation challenge the lack of protection of the land use and tenure of communities, such as the Batwas, who are indigenous and forest dependent in Uganda (ACHPR and IWGIA 2005, p. 17). While it uses the word "indigenous" in describing "indigenous knowledge," it is used to refer to every citizen of Uganda. This is the logical inference that can be drawn when the term "indigenous" is examined in the sense that it is used in the Uganda 2005 Constitution. According to article 10 (a) of the constitution of Uganda, all the communities found in Uganda as on February 1, 1926, are indigenous. The NAPA employs the concept of "vulnerability" and "indigenous" in referring to all the communities in Uganda without paying attention to the peculiar situations or circumstances of specific groups such as the Batwas who are understood under international human rights law as "indigenous" in Uganda (ACHPR and IWGIA 2005, p. 17).

Tanzania

There is a similar trend in the NAPA of Tanzania, which was submitted in 2007 (Tanzania NAPA). The document indicates the adaptation concerns in Tanzania as including "loss of human, natural, financial, social and physical capital, caused by the adverse impacts of climate change." It also documents "severe droughts and floods, among many other disasters" (Tanzania NAPA 2007, VI). It is further mentioned in the NAPA that climate change is expected to further shrink the rangelands which are significant for livestock-keeping communities in Tanzania (Tanzania NAPA 2007, p. 7). While this may be argued as embodying some of the concerns of indigenous peoples in Tanzania such as the Maasai and Barabaig (ACHPR and IWGIA 2005, p. 17), it is not certain. This is because it proposes as adaptation measures the inclusion of some activities such as relocation of people living in wildlife corridors, zero grazing, and development of alternative means of income for communities in tourist areas (Tanzania NAPA 2007, pp. 29–31). These activities will disrupt the culture and lead to the displacement of indigenous peoples such as the Maasai and Barabaig in Tanzania and hence threaten their land use and local adaptive practices.

Nigeria

Nigeria is a non-LDC state and has shown no interest yet in filing a NAPA as a non-LDC. It has, however, filed a national communication which devotes a substantial attention to issues of adaptation in the country. In the communication which is the first and only national communication it has so far lodged under the UNFCCC, peculiar consequences resulting from climate change, and which require adaptive measures, include soil erosion and flooding in the southeastern part of the country. The impacts of climate change on agriculture are assessed as including the effects of changes in temperature and rainfall on plants and animals as well as sea level rise on agricultural land (Nigeria First National Communication 2003, p. 73). Livestock production also suffers due to a decrease in rainfall which has led to a decline of pastureland and water resources (Nigeria First National Communication 2003, p. 75). Sea level rise is also cited as an event likely to lead to considerable losses in the oil investments and developments in the Niger Delta zone. General reference is made to "the people in the coastal areas" as being impacted by challenges such as flooding and erosion in the Niger Delta and leading to the emergence of "environmental refugees" (Nigeria First National Communication 2003, p. 82).

Nonetheless, the Nigeria's national communication largely focuses on the environmental impacts of climate change, relying "heavily on. . .existing records and documentation in various forms including socio-economic statistics, photographs, satellite imageries, geologic and oceanographic data, biological and fisheries data. . ." (Nigeria First National Communication 2003, p. 70). Generally, communities affected by these impacts are not mentioned nor are the pertinent issues such as land use, land tenure, and resource rights relating to these communities discussed. For instance, a decline in pastureland as a result of climate change will not only affect the production of livestock, but it will negatively impact the peoples such as the Mbororo whose lifestyle is traditionally connected to the use of land for cattle rearing. Also, the passing reference to the people living in coastal areas as likely to experience flooding and erosion does not capture the larger problems which the peoples of this region, particularly the Ogoni, have for long faced and fought in terms of oil spillage, environmental protection, and compensation for environmental losses and land degradation on their land (Nzeadibe et al. 2011). It is difficult to anticipate that a national communication which fails to reflect key issues peculiar to these indigenous peoples will, even if allocated, apply adaptation funds for the purpose of supporting their adaptive practices and concerns.

What emerges from the foregoing discussion are therefore the reasons why states in Africa neglect indigenous peoples' concerns and land-based experiences in framing adaptation processes at national level.

Basis for State's Exclusion

The approach by states of Africa in engaging adaptive processes in a way that strengthens adaptive practices and addresses the adaptive concerns of indigenous peoples is arguably shaped by two factors. These are the state-centered nature of the processes and the overriding claim to ownership of land and disposition to use same in accordance with its priority.

State-Centered Process

The UNFCCC and the Kyoto Protocol and indeed decisions of the COP and MOP, respectively, are state centered. In line with article 2 (1) (a) of the Vienna Convention which describes a treaty as an agreement concluded between states (UN 2005), the parties to the international negotiation of climate change instruments such as the UNFCCC and the Kyoto Protocol are states and not community or group of people. Also, the Conference of the Parties (COP) which is the key decision-making body under the UNFCCC or the Meeting of the Parties (MOP) to the Kyoto Protocol which makes the ultimate decisions in respect of climate change and response mechanisms is state based representing the interest of different negotiation blocs and states.

The decisions of these bodies emphasize the "country-driven" nature of adaptation measures. For instance, the Cancun Agreement which serves as the basis for enhanced action on adaptation involving the developing country parties endorses this approach. It urges parties to strengthen and, in applicable circumstances, establish centers and networks to facilitate and enhance national and regional adaptation actions, in a manner that is country driven and with support from developed countries (Decision 1/CP.16/2010, p. 30).

This state-centered nature of adaptation processes also applies to funds relating to adaptation. For instance, the AF (Decision 1/CMP.4/2008, p. 11), GCF (Decision 3/CP.17/2011, p. 31), LDCF, and SCCF (Xing and Fröde 2012; Bird et al. 2011) support direct access to adaptation funds. By "direct access," it is meant that these funds allow recipient countries to access financial resources, unlike the indirect access, where funding is channeled through a third-party implementing agency (Xing and Fröde 2012). However, this challenges the adaptation potentials of land use by the indigenous peoples in Africa. This is because the notion of direct access is understood in terms of the ownership of these funds by the state. This is clear, for instance, in the recommendations made by the African Development Bank (AfDB) on GCF where it employs the term "direct access" to fund largely as accessibility by national governments (AfDB 2012, p. 3). Also, according to the *Operational Policies and Guidelines for Parties to Access Resources from the Adaptation Fund* (AF Guidelines 2013), projects may only be submitted and funds received directly by the national implementing entity (NIE) which may consist of government ministries and government cooperation agencies (AF Guidelines 2013, para 27).

The implication of state-centered focus of adaptation process is that it is coordinated by the states as has been shown and thus compromises ownership of process by indigenous peoples in Africa. Also, the lack of direct access to funds is that it undermines the utility of indigenous peoples' adaptive practices and may, as climate change worsens, compromise their opportunity to strengthen capacity. Yet, an arrangement enabling indigenous peoples a direct access to funds is not unknown to the operation of some financial institutions. For instance, models on direct access to funds for indigenous peoples exist under the International Fund for Agricultural Development (IFAD); Indigenous Peoples Assistance Facility (IPAF), a former World Bank Facility for Indigenous Peoples; and the Forest Carbon Partnership Facility (FCPF) which has a Capacity Building Program for Forest-Dependent People, all of which are dedicated indigenous funds (Martone and Rubis 2012).

National Legal Framework

In addition to the above, in Africa, key legal and policy framework relating to land use and tenure of indigenous peoples generally vests ownership of land in the state. For instance, article 44 of the Uganda Land Act (1998), articles 1 and 2 of Nigeria Land Use Act (1990), article 3 of Zambia Lands Act (1995), and Tanzania Land Act (1999) vest in the state the power to own and use land in accordance with its priority. This is similarly the case with the Forest Act of states in Africa which assumes the forests as "common goods." Accordingly, articles 3, 10, and 11 of the Forests Act of Zambia (1999), respectively, vest the ownership of every tree and its produce in the presidency, which enjoys the power to compulsorily acquire any land for the purpose of national forests and restricts the activities of peoples dependent on land such as fishing and hunting from compensation. Article 26 of the Tanzania Forest Act prohibits every action of indigenous peoples that can be regarded as of adaptation relevance such as grazing, hunting and fishing, and erection of any buildings or other structures except with the permission of the minister or a local authority. According to article 5 (1) of the Uganda's National Forestry and Tree Planting Act (2003), the state at different levels of governance is empowered to hold the forests in trust for the common good of Uganda. Also, according to the National Forest Policy of Nigeria (2006, p. 68), the government is empowered to hold in trust the forest set aside as reserve lands.

While there are few exceptions within the legal framework on state ownership and control of land, this is often rendered redundant in the face of overriding public interest. Hence, the general implication of this land and forest regime is that government can legally own and use land for different priorities other than the strengthening of adaptive practices of indigenous peoples. For instance, this enables the state to pursue interests such as large-scale agricultural plantations, mining and logging, construction of roads and dams, as well as conservation which are often at cross-purposes with indigenous peoples' adaptive practices. In addition to land degradation, the consequence of these activities for indigenous peoples is displacement from the land or territories to which they are culturally attached. This can be buttressed by the presence and consequences of such projects on indigenous peoples' land in Africa.

Large-scale agricultural plantations in several states of Africa including Benin, Ghana, Cameroon, Kenya, Tanzania, Mozambique, Namibia, and Ethiopia do not only disrupt the land use of indigenous peoples but also compromise their tenure rights (Vermeulen and Cotula 2010). In particular, according to Laltaika (2009), massive Jatropha plantations are a new threat to the survival and livelihood of the Maasai in Tanzania. Through concession to private or public business, including logging and mining companies, the land regime also allows mining and logging activities on indigenous peoples' lands (Barume 2010, p. 70). In the Niger Delta region of Nigeria, which is rich in crude oil, oil exploration on the land of indigenous peoples such as the Ogoni, Efik, and Ijaw (ACHPR and IWGIA 2005, p. 18) has occasioned environmental degradation resulting from activities including gas flaring and deforestation (Oruonye 2012). Kidd and Kenrick (2009, p. 21) found that the Exxon's World Bank oil pipeline project backed by the government in Chad and Cameroon which crossed Bagyéli land at least five times in the Bipindi area has severe impacts on these communities. These include their displacement and destruction of sacred sites and way of life.

Roads and dam constructions have all played a part in the destruction of forests (rainforest deforestation), which are crucial to the shelter, survival, and livelihood of some indigenous peoples. In Namibia, the construction of dam at Epupa was considered environmentally and socially attractive but would displace 1,100 Himba and affect 5,000 occasional users of the grazing areas on the river bank, in addition to the loss of their cultural and religious sites (World Rainforest Movement 2013, p. 28). Conservation efforts in Central Africa have equally led to the dispossession and poverty of indigenous peoples such as the Batwas in that part of Africa. According to Cernea and Schmidt-Soltau (2006), the trend in this regard has been ongoing for long, taking place without due regard for consultation and compensation for forced removal.

Essentially, this land regime allows the states in Africa to deflate their responsibilities toward indigenous peoples' immediate adaptation concerns in the guise of accessing, using, and controlling land for public good. It is thus no surprise that, at international climate forum, indigenous peoples have made the claim for protection of land as key in climate change responses including adaptation. At Nakuru, Kenya, indigenous peoples, particularly of Africa, urge intergovernmental organizations, UN agencies, and international organizations and foundations to ensure that the principles of the UNDRIP are mainstreamed in the design and implementation of any program or project in their land (Nakuru Declaration 2009). At Anchorage, in addition to emphasizing the need for security of land of indigenous peoples as critical to climate programs, indigenous peoples call for adequate and direct funding to enable them to participate effectively in all projects or programs including adaptation (The Anchorage Declaration 2009, pp. 5–7). Also, the International Indigenous Peoples' Forum on Climate Change (IIPFCC) in its closing statement before the 2012 SBSTA Working Group meeting calls for the strengthening of the adaptive strategies of indigenous peoples with appropriate policy framework which respect their rights to land and traditional practices (UNFCCC 2012).

Conclusions

This chapter makes a case for the necessity for states to have in place adaptation policy in Africa. It bases this proposition on three premises. The first foundation is that there are existent adaptive practices of indigenous peoples which had been useful in coping with adverse range of climate conditions. These adaptive practices which are closely linked to the cultural relationship of indigenous peoples with their land include approaches in form of prediction of weather, water security, drought and land degradation management skills, and food preservation. The second premise is that indigenous peoples in Africa now face a new range of climatic variations beyond their coping adaptive capability. As the final basis of the argument, the chapter demonstrates that rather than addressing this situation, in engaging with international adaptation processes, states in Africa do not facilitate the profiling of indigenous peoples' adaptive challenges and the development of their land-related adaptive practices. Thus, the foregoing premises justify the necessity of formulating appropriate policy to safeguard indigenous peoples through "land-sensitive" adaptation policy in different states in Africa.

Basic policy framework should include the recognition of indigenous peoples' identity, land use, and land tenure as critical to adaptation approach. In line with UNDRIP principles of participation and benefit sharing and protection of land rights (UNDRIP 2007, art 26), it should reflect the vulnerability of indigenous peoples while engaging with international adaptation processes. Along similar line, it should include indigenous peoples in the framework for implementation of adaptation policy, grant them direct access to funds and culturally acceptable technology, address climate threats to their land, and commit funds for successful design and/or implementation of programs and projects under NAPA and national communications. Adaptation policy measure at the national level should include the recognition of indigenous peoples' traditional institution structure in accessing funds for the implementation of adaptation projects and secure their land access and tenure. All this is important, not only for the purpose of giving hope to indigenous peoples who may yet face a somber future of difficult climate variability but because it will help states in Africa in investing time and resources into where they are needed most.

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Climate Migration Governance

Benoît Mayer

Contents

Abstract

This chapter engages with the current political and academic debate on the governance of "climate migration." It highlights the difficulties of ascribing a unique cause to migration and questions the relevance of distinguishing "climate migration" from other forms of migration. It then exposes the opportunities and challenges of this concept for international cooperation. Finally, it assesses the potential of different policy options. Despite the difficulties related to the attribution of migration to a unique driver, the concept of "climate migration" appears as a powerful communicative strategy to trigger important international and domestic actions with regard to climate change adaptation and to the protection of the rights of migrants, even though a specific legal regime remains unlikely and perhaps undesirable.

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Introduction

Every society comprises migrants. Individuals migrate in response to a multitude of factors – political, economic, social, cultural, demographic, or environmental. The impacts of climate change on the environment and societies are therefore likely to have consequences on the way people migrate or do not migrate.

Since the late 1980s, a literature has developed on a new issue, first labeled "environmental migration" (i.e., migration attributed to environmental factors) but soon refurbished as "climate migration" (i.e., environmental migration that can be attributed to climate change) as climate change was attracting an increasing amount of public attention. Norman Myers ventured to predict the number of "environmental refugees" in the coming decades: 150 millions (Myers 1993), 200 millions (Myers 2002), or 250 millions (Myers 2007). Climate change affects the probability of slow-onset environmental changes (desertification, land degradation, sea-level rise) and sudden-onset events (cyclone, storm surge, etc.), and both of them may have an impact on migration. Walter Kälin distinguished between five scenarios leading to environmental migration: (1) "*sudden-onset disasters*, such as flooding, windstorms [. . .] or mudslides caused by heavy rainfalls"; (2) "*slow-onset environmental degradation* caused, inter alia, by rising sea levels, increased salinisation of groundwater and soil, long-term effects of recurrent flooding, thawing of permafrost, as well as droughts and desertification"; (3) "so-called '*sinking*' *small island states*"; (4) areas designated by governments as "*high-risk zones* too dangerous for human habitation on account of environmental dangers"; and (5) displacement following "unrest seriously disturbing public order, violence or even armed conflict" that "may be triggered, at least partially, by a decrease in essential resources due to climate change" (Kälin 2010). The concept of "climate migration," more specifically, reflects a growing understanding that, climate change affecting a large array of human activities, climate change governance needs to expand beyond, in particular beyond in situ adaptation.

On this understanding of climate change-induced migration, political scientists and lawyers suggested solutions directed to address the vulnerability of "climate migrants," mostly conceived as forced and international migrants. By analogy to the Convention relating to the Status of Refugees adopted in Geneva in 1951 (Refugee Convention), Biermann and Boas proposed an international "climate refugee" convention to "prepar[e] for a warmer world" (Biermann and Boas 2010). A group of French lawyers even designed a ready-to-sign project of convention (CRIDEAU 2008). Discussions were initiated in multiple domestic or regional political constituencies, although the adoption of a multilateral treaty never really appeared as a realistic option (Mayer 2011; McAdam 2011).

A more cautious, "skeptical" school came to dominate the literature (Morrissey 2009). This school has three main credos. Firstly, it insists on the diversity of the migration strategies that are affected by climate change. In particular, internal migration (i.e., within a state) must be distinguished from international migration (i.e., across international borders). Both raise significantly different legal issues, as internal migrants remain within the jurisdiction of a same state responsible for the realization of their human rights, whereas international migrants need to be admitted to a third country. In most circumstances, the effects of climate change are limited to internal migration (EACH-FOR 2009; UNU 2012), and they are particularly unlikely to trigger significant long-distance migration flows. The exception relates to the hypothesis that small, low-lying island developing states such as the Maldives or Tuvalu may become uninhabitable because of sea-level rise, drought, more extreme and frequent weather events, and the impact of the acidification of the ocean.

Secondly, this “skeptical” school rejects a simple and direct causal link through which climate change would force individuals to migrate. In 2001, Richard Black already opposed the “multiple and overlapping causes of most migration streams” to Myer’s alarmist predictions (Black 2001). Just as there is no purely “natural” disaster, the impacts of climate change depend on the social, political, economic, demographic, and cultural factors that define a society’s vulnerability. Nor does any more or less “natural” disaster determine a migratory behavior: different societies and different individuals react in various ways to the same events. Rather than the driver of a specific form of migration, the impact of climate change appears now as one in a cluster of causes; rather than purely “forced migration,” climate migration may range on a continuum between voluntary and forced migration (Hugo 1996).

Thirdly, and largely as a consequence of this, the “skeptical” school questions our capacity to identify individual “climate migrants,” as would be necessary if a personal status was to be granted. An influential report to the British Foresight agency concludes that “the range and complexity of the interactions between the [multiple economic, social and demographic] drivers means that it will rarely be possible to distinguish individuals for whom environmental factors are the sole driver (‘environmental migrants’)” (Foresight 2011).

This credo makes it virtually impossible to conceive the governance of climate migration by analogy with that of international protection of refugees through the conference of an individual status. Under the Refugee Convention, a refugee is a person who (1) “is outside the country of his nationality” or habitual residence and (2) “owing to well-founded fear of being persecuted for reasons of race, religion, nationality, membership of a particular social group or political opinion, . . . is unable or . . . unwilling to avail himself of the protection of that country” (1951 art. 1(A)(2)). Climate migrants do not normally qualify, even the few who cross an international border, because it is difficult to conceive climate change as a form of persecution and if this was the case, such “persecution” could not be related to one of the five grounds enumerated in the Convention (McAdam 2012), and in most cases there would likely be reasonable internal flight alternatives. The legal definition of a “refugee” can however be extended to other individuals, fleeing for instance situations of generalized violence, as has been done regionally in particular in Africa, Latin America, and Europe (McAdam 2007); a further extension to other forced migrants could certainly be considered – but this would only address a small part of the issue, letting aside the vast majority of internal migrants affected by the impacts of climate change.

In what follows, I question the possible responses that international governance can realistically bring to address climate migration. This requires a more thorough look at certain difficulties that relate to "climate migration," a concept that appears as impractical, arbitrary, yet promising.

Conceiving Climate Migration: From Ethics to Norm Entrepreneurship

Practical and Conceptual Difficulties

It is difficult to reconcile the concept of "climate migration" with the understanding that migrations result from a multitude of factors (Lee 1966). The abovementioned report to the Foresight agency concluded that "[e]nvironmental change is equally likely to make migration less possible as more probable" (Foresight 2011), in particular because environmental stress may decrease the resources available to a population and consequently deprive individuals from the capacity to invest in the costs of migrating – including travel expenses, dangers, and temporary unavailability of income (Brown 2007). On the other hand, the same environmental stress may increase the need for income diversification. Which tendency will prevail – less migration because of resource deprivation or more migration for resource diversification – depends on the complex circumstances that define each case at the domestic, local, and individual scale. Similarly, insecurity may be a factor of migration in some cases, but the fear of land-grabbing or theft may also force individuals to remain or rapidly return in the vicinity of their property after an environmental disaster. More generally, the ability and propensity of individuals displaced by a disaster to return to their place of origin depends, among others, on social resilience (e.g., the reconstruction of infrastructures in the place of origin) and on the capacity of the displaced individuals to integrate in the place of destination.

Following the earthquake that struck Lisbon in the mid-eighteenth century, French philosopher Rousseau (1756) disputed Voltaire's blame of the Providence; accordingly, "it was hardly nature who assembled there twenty-thousand houses of six or seven stories." Natural disasters result from a combination of physical elements on which humans have no direct control (although they have an indirect control on global anthropogenic climate change) and social elements that define the vulnerability of a society. Future numbers of migrants who can be attributed to climate change depend on many political, economic, social, cultural, and demographic factors. In particular, demographic growth will have an influence on the number of persons affected by any environmental change and so will also any policies that have an impact on the distribution of a population within a territory (Hugo 2011). Development also plays an important role: a country such as Bangladesh is vulnerable to sea-level rise because of its exposure (low altitude of most of its territory) but also because it does not have financial capacities comparable to the Netherlands to build dikes and seawalls. In some countries, the adverse effects of climate change may significantly impact the economy, thus further increasing the country's vulnerability to climate change.

Nonetheless, there are some estimates of the numbers of individuals displaced by sudden-onset natural disasters. The Internal Displacement Monitoring Centre (IDMC) estimates that between 2008 and 2012, an average of 29 million persons had been displaced each year (143.9 million persons in 5 years) by such rapid-onset natural disasters, although not all countries reported (Yonetani 2013). Eighty-two percent of these persons were in Asia, 9 % in the Americas, and another 9 % in Africa. Moreover, 16.7 % were displaced due to geophysical disasters (e.g., earthquakes, tsunamis) that are not a priori related to the climate, while the remaining 83.3 % were displaced by weather-related disasters, comprising 62.4 % displaced by hydrological disasters (e.g., floods, wet mass movements), 20.2 % by meteorological disasters (e.g., storms), and 0.7 % by climatological disasters (e.g., extreme winter conditions, heat waves, etc.) (Yonetani 2013). These statistics are produced by estimating the number of persons displaced following a disaster, thus ignoring the contribution of different factors in creating a “natural disaster.”

On the other hand, however, this approach cannot readily be applied to measure the consequences of the diffuse economic impact of slow-onset environmental disasters such as sea-level rise, land degradation, desertification, or droughts. If some contend that environmental degradation may have consequences on security, possibly making conflict escalation more likely through increased competition for essential resources, the number of additional migrants that can be attributed to environmental degradation would also be particularly difficult to measure – and identifying individual migrants would be virtually impossible. Often, the migratory impact of environmental changes is statistical (increased numbers) but cannot be established at the individual level through an individual status determination procedure.

Beside the difficulty of attributing individual migrants to a “natural disaster,” there is a difficulty in attributing a “natural disaster” to climate change. A media and political discourse has attributed super typhoon Haiyan that struck the Philippines in November 2013 to climate change, although scientific evidence only suggests that cyclones might become less frequent but more violent (IPCC 2014, 216–217 (Sect. 2.6.3), 913–614 (Sect. 10.6.1.5)). Nor can climate change be considered as the cause of the 2010 monsoon floods in affected China that IDMC identifies as the greatest displacement (15.2 million persons) between 2008 and 2012 (Yonetani 2013). Besides the inevitable element of scientific uncertainty of the climate models, the scientific community only asserts that “global monsoon precipitation will likely strengthen” (IPCC 2014, 1234 Sect. 14.2.5), saying that the *probability* of such floods increasing does not mean that a specific flood is *caused* by climate change. In other words, the statistical concept of climate (change) does not allow for the binary determination of whether or not a disaster is caused by climate change and, even less, whether or not an individual is a “climate migrant.”

Therefore, “climate migration,” as individuals displaced because of climate change and who can be distinguished from economic migrants and treated differently, is an impractical concept. Dramatic but controversial forecasts of small island developing states being submerged by sea-level rise draw a wrong picture of environmental changes as direct, isolable factors of migration, letting little to no place for human agency (Farbotko 2005; Gemenne 2010; Kälin 2010). Whereas refugees are often opposed to "voluntary" economic migrants, environmentally induced displacement is not distinct from economic migration: most "climate migrants" *are*, indeed, economic migrants, as economic factors are the most proximate cause of their flight. This should not, however, mean that environmental change does not "force" people to move, but rather that the dichotomy between "voluntary" economic migrants and "forced" refugees is artificial: economic conditions leading to migration, be they triggered by an environmental change or not, can be and often are tragic.

Discourse Inconsistencies

The concept of climate migration is not only impractical: it is also arbitrary. No valid ethical discourse seems able to plead for a governance of climate migration rather than for responses to larger issues. To support this claim, three narratives can be identified: one on the protection of the rights of climate migrants as migrants (rights narrative), another one on the responsibility of polluting states for the adverse impacts of climate migration (responsibility narrative), and the last one on conceiving climate migration as a security issue (security narrative) (Mayer 2012a). Each of these three narratives is rooted in a different disciplinary background and leads to a different justification for an engagement of the international community, but none of them identify climate migration as a unique issue needing a specific form of governance.

Firstly, the rights narrative often relates to a broader humanitarian discourse, conceiving the governance of climate migration as essentially a question of international solidarity. It puts forward the need for the protection of climate migrants. It proposes in particular an analogy between refugees and climate migrants, suggesting either to expand to the latter the protection that benefits many of the former or to create an alternative system of protection. Many such works call for an ambitious engagement of the international community to protect environmental migrants (Bell 2004; Brindal 2007). However, what this narrative really looks at is not climate migrants, but forced migrants. Limiting a new instrument to "climate migrants" (besides being impractical) would reproduce the arbitrary distinction between refugees and other forced migrants. The rights narrative addresses vulnerability, but the cause of vulnerability is irrelevant. If this narrative focuses on international migration, then Betts' argument for a protection of "survival migrants" is more coherent (Betts 2013); if it turns to internal migration, then it should propose mechanisms to reinforce the protection of internal migrants. Furthermore, the rights narrative cannot ignore that migrants are generally *not* the most vulnerable in a society, as the poorer often lack the resources necessary to move (Foresight 2011) – this issue of the "invisibility" of more vulnerable nonmigrants is well known in other situations of forced migration (Lubkemann 2008). In a humanitarian perspective, many climate migrants should certainly be of concern, but any governance endeavor limited to climate migrants would be arbitrary: other migrants in a similar situation of vulnerability and arguably, even more, those "trapped in place" should also be of concern.

Secondly, the responsibility narrative highlights the inequity that results from the poor, who benefit the less from greenhouse gas emissions, being the most severely affected by anthropogenic climate change. There are multiple technical hurdles to the legal argument that Tuvalu and Palau considered to bring to the International Court of Justice and that the inhabitants of Kivalina, an Alaskan village displaced because of the melting of a natural seawall, brought before American courts against multinational companies (Ielemia 2007; Kysar 2011). The ethical argument, however, is relatively straightforward, even through its modalities such as the discounting of past emissions, the possible excuse of ignorance, or the level of excusable emissions are subject to debates (Shue 1999; Caney 2005). Migration might be one of the adverse effects of climate change, and it was identified as such during recent international negotiations on loss and damage associated with the adverse impacts of climate change (UNFCCC 2012). Yet arguments for the responsibility of greenhouse gas emitters do not lead specifically to the governance of climate migration. The responsible parties ought arguably to cease their wrongful conduct and to repair the harm they already caused (see by analogy ILC 2001), but responsibility can in no case justify the imposition of specific norms on the injured parties. How to respond to migration through climate change adaptation policies should be within the sovereign prerogatives of each state, as long as this state complies with its general international obligations such as under international human rights law. Specific humanitarian standards may be desirable, as the rights narrative suggests, but they should not be specific to climate migration, as mentioned above.

Thirdly, the security narrative, constructed by military and intelligence research, approaches climate migration in a very different way by putting forward the interests of powerful actors (generally states, but also possibly corporations) rather than their ethical duties. This narrative contends in particular that states should act early in order to prevent future political instability and that they should cooperate in order to avoid illegal migration and the concomitant development of issues such as drug or human trafficking, failing states and wars affecting commercial interests overseas, and international terrorism (e.g., Söderblom 2008). In other words, states should cooperate because this is in their own, well-understood interests. This narrative may come along with an incentive to militarization, although some have tried to reframe climate migration as rather a "human security" issue (Elliott 2010). Here again, however, it is not evident how climate migration appears as a different sort of issue from other humanitarian situations leading to migration, most obviously in cases of non-climate-related environmental disasters. When a state goes through a spiral of environmental, economic, political, and military issues leading to its failure to protect its population, the contribution of climate change to this spiral is irrelevant in terms of international security. At most, by possibly making such scenarios more likely, climate change calls for more attention to larger security issues.

Momentum for Change

Because the concept of climate migration is both impractical and arbitrary, Betts (2013) and Nicholson (2014) have suggested abandoning it altogether. Consistency would dictate the definition of different issues: the rights narrative suggests a governance of migration or forced migration; the responsibility narrative calls for a commitment of greenhouse gas emitters toward mitigation and compensation, arguably not only through adaptation but also through a substantial loss and damage mechanism; and the security narrative calls for international cooperation reflective of our growing complex interdependence.

The problem is that neither the rights nor the responsibility narratives are very effective on their own as both are ethical arguments about what actors *should* do – and actors do not always do what they should. In particular, these two narratives are grounded in cosmopolitan ethics or "global justice" theories that are yet to be fully endorsed by sovereign states: international governance remains grounded on the concept of sovereign states pursuing their own interests, the rebirth of autocratic monarchs "owing" their country. Within the climate regime, for instance, the responsibility narrative is less influential than the interests of each state (Posner and Weisbach 2010); it is in particular on a purely voluntary basis that states commit (or not) to contribute to mitigation, only vaguely guided by the UN Framework Convention on Climate Change's ambiguous references to principles of "equity" and "common but differentiated responsibilities and respective capabilities" (art. 3.1). The recent negotiations on a loss and damage mechanism show the fierce opposition of developed states to anything approaching compensation, despite compelling ethical arguments.

On the other hand, the security narrative is able to create a political momentum by "speaking to states' interests," that is, by explaining why states could be motivated in doing something that happens also to be ethically sound. James Hathaway (1990) demonstrated that the international refugee regime was not developed out of pure generosity (how could the limitation of the definition of a refugee to persons persecuted on a specific ground be explained?), but rather because of the conjunction of a humanitarian narrative with a persuasive interpretation of states' interests, generating a shared willingness to "govern disruptions of regulated international migration in accordance with the interests of states," "a compromise between the sovereign prerogative of states to control immigration and the reality of coerced movements of persons at risk." Hathaway's conception of the rationale of the refugee regime suggests an alternative analogy with climate migration, not on the substance by pleading for the expansion of a regime already running out of political support but rather on the method of constructing a political support, a momentum for change, by joining ethical arguments with an interpretation of the states' own interests.

Despite its logical inconsistencies, the case for climate migration appears as a magical recipe for norm entrepreneurs (Mayer 2014). There is no essential reason why migrants should be protected rather than other vulnerable people, but migrants attract more attention, if only because of the fear that they may be approaching "us." Nor is there any reason to focus on climate migrants specifically – other environmental migrants are most obviously in a similar situation of human suffering – but anything related to climate change attracts a unique degree of public attention and, possibly, of engagement. By joining the deep-rooted fears of migration with the existential uncertainties raised by climate change, climate migration has an immense marketing potential.

Climate change fuels fears that, if well directed by skillful norm entrepreneurs, may be overcome through fair international cooperation. Similar moments of doubt, such as the end of the Second World War, led to great progress for international governance – including the formalization of the international refugee regime. The same could be done today, in response to climate change, with regard to larger populations of unprotected migrants or other vulnerable individuals throughout the world. Climate migration might not be a practical or consistent concept, but it is a popular one – it is a concept that may trigger a first step toward fairer international cooperation.

The Challenges of Governing Climate Migration

Reconciling the Fair and the Realistic

Governing climate migration poses a broad challenge: how to reconcile the sovereign rights of states with the human rights of climate migrants or, more broadly, of any migrants or anyone affected by climate change? Meaningful preliminary steps have been made to realize the rights of all migrants and to promote cooperation with regard to climate change, but new steps need to be conceived.

The control of migration has generally been conceived as the preserve of states, despite some ethical arguments for an opening of international borders (Carens 1987). A report of the UN High Commissioner for Human Rights on the relationship between climate change and human rights clearly recognized that persons affected by climate change "would often not have a right of entry" to another state (OHCHR 2009). As noted before, the refugee regime has arguably been developed as the exception that reinforces the rule. The Universal Declaration of Human Rights (1948), however, confers to everyone "the right to freedom of movement and residence within the borders of each State," although the International Covenant on Civil and Political Rights (1966) allowed for restrictions of this right "which are provided by law [and] are necessary to protect national security, public order . . ., public health or morals or the rights and freedoms of others."

More than the right to move, however, it is often the many other rights of the migrants that are at issue: right to health, education, decent conditions of living, certain economic opportunities, etc. Both the UN Human Rights Council and the Conference of the Parties (COP) to the UN Framework Convention on Climate Change recognized that the adverse effects of climate change have a range of direct and indirect implications for the effective enjoyment of human rights (HRC 2008, 2009, 2011; UNFCCC 2010). Migrants, as human beings, are protected under international human rights law like anyone else; foreigners benefit from all human rights with the sole exceptions of the right to vote and to be elected and the right to enter a country (OHCHR 2009). The International Convention on the Protection of the Rights of All Migrant Workers and Members of their Families was adopted in 1990 in order to emphasize the human rights of all migrants, including those who lack regular documentation. It is significant that, after 23 years, no more than 47 states ratified this convention (as of January 2014). Regarding internal migrants, the Guiding Principles on Internal Displacement adopted by the UN Commission on Human Rights in 1998 clarified and promoted state human rights obligations, and the African Union Convention for the Protection and Assistance of Internally Displaced Persons in Africa adopted in Kampala in 2009 and entered into force on 6 December 2012 (Kampala Convention) is an important development in a regional context.

The lack of capacities of local governments may however significantly hinder the realization of human rights, in particular by limiting the implementation of programs of humanitarian assistance that are costly but indispensable. This might be specifically the case for developing states that are particularly vulnerable to the adverse effects of climate change, whose capacities may shrink while needs expand. The general reliance of international human rights law on the obligation of each state to protect the persons within its jurisdiction is inadequate to address the circumstances where the impacts of climate change may affect a state as a whole. Existing mechanisms of humanitarian assistance and aid to development are of paramount importance, but they are also strikingly insufficient, attached with detrimental conditions and extraneous political priorities, and contingent to inconsistent levels of public attention (Fassin 2012; GHA 2013).

Linking migration with climate change, however, suggests that the human rights of migrants could more efficiently be implemented through international cooperation. Climate change is by essence a global issue, the substantiation of our growing complex interdependence (Singer 2004). It is also by essence a moral issue, through which the action of some causes harm to others, although in a complex manner (Gardiner 2011). The wide gap between the "haves" and the "have-nots" in terms of historical or present emissions and the concentration of most of the physical and social impacts on the "have-nots" ground a compelling case for not only a form of international solidarity but also for a full-fledged causal (tort-like) responsibility. The ethical responsibility of greenhouse gas emitters substantiates demands for international cooperation in the realization of human rights, not as a "soft duty" of humanitarian assistance but as a "hard duty" of compensation: aid is a due, not a charity.

Yet such ethical arguments are unlikely to have a substantial political impact on their own. NGOs, intellectuals, and some politicians play an important role in raising public awareness, and public opinions may contribute to frame international politics. The success of the International Campaign to Ban Landmines in the 1990s, despite the economic interests of weapon-exporting developed states, evidences the ability of relatively powerless actors, as "norm entrepreneurs," to impact public opinion and thus to shape international relations (Wexler 2003). Yet the interests at stake with regard to climate change far exceed the concessions that some developed states made with regard to the exportation of landmines. Ethical arguments, even if accompanied with a high degree of pathos, will not suffice to convince any democratic government to make the economic sacrifices necessary to fully compensate affected countries. An advocacy that is solely based on the rights of climate migrants and the ethical obligations of other states toward them is unlikely to lead to anything else than an increase in humanitarian assistance. Some American scholars argue that ethical arguments impede international negotiations and should be avoided: rather, states should openly seek their own interests (Posner and Weisbach 2010). This is a dead end, for rational, profit-seeking states are likely *not* to participate in a climate treaty, preferring to free ride over the sacrifices of other states.

The flaw in the arguments based on states' interests is that these "interests" are assumed to be known, uncontroversial givens. There is in particular a tendency to equate "interests" with "rational economic interests" that economists can calculate. Yet the economic value of avoiding climate change is difficult to evaluate, not only because of scientific uncertainty and contingence to a range of other processes such as development but also because there is no agreement as to how future costs should be discounted (Nordhaus 2007). Furthermore, states are also prone to take noneconomic interests into account, especially when discussing an issue such as climate change with potential tremendous security consequences. Unaddressed disasters may conceivably contribute to induce famines, extreme poverty, epidemics, failing states, conflicts, and terrorism, which will have consequences in the whole of an interdependent world. Just like there is no one rational magical formula to discount future events, there is also no such formula to measure existential risks. How much a state is willing to invest today in order to address such undefined future security risks depends on a complex process of political deliberation, in particular social and cultural settings. The current divergence between the European Union and the United States in climate negotiations reflects different political deliberation rather than radically different economic interests.

As long as states' interests are opposed to their ethical obligations, these ethical obligations will be left behind. It may therefore be advisable for norm entrepreneurs to focus on reinterpreting the interests of states in terms that are at least *roughly* ethical. Linking climate migration to security may appear as a promising strategy to trigger change. Under the influence of this discourse, the UN Security Council has already discussed the impact of climate change on international peace and security and requested a report of the Secretary-General on this topic (UN Secretary General 2009). The same discourse, however, has also been used to justify US military investments in Africa (Hartmann 2010) or India to fence part of its border with Bangladesh – but containment is not a sustainable response to humanitarian crises. Contemporary history shows that no crisis is set to remain purely domestic. The neglecting of the Afghan humanitarian crisis by the rest of the world over the last decades of the twentieth century allowed the development of a terrorist movement that led to the worst terrorist attacks in the United States. It is rather through an intense and responsible investment in human development that the international community may reduce threats to international peace and security.

Possible Steps Forward

Some form of international governance might be both realistic and desirable and, indeed, is already being discussed. Proposals for an international treaty that would be inspired by the Refugee Convention and would establish an individual status for international climate migrants, or forced migrants more generally, are not among such realistic and desirable steps. It is unlikely that states will agree to bind themselves to provide international protection to an unknown number of future migrants. Many states that have ratified the Refugee Convention are increasingly reluctant to comply with the specific obligations that it defines. Furthermore, whereas it is in Asia that climate change has the impact on migration, few Asian states are party to the Refugee Convention – even fewer would possibly ratify a convention protecting any broader categories of migrants (Mayer 2012b).

The adoption of a treaty promoting the rights of internal migrants is less unlikely, as the recent entry into force of the Kampala Convention shows, and it might be desirable. As it would be impossible and arbitrary to distinguish "climate migrants" within the flow of internal migrants, such a treaty should extend to all internal migrants. Such a treaty would essentially interpret and repeat the existing obligations of states under treaty and customary international human rights law rather than create brand new rights and obligations – for it is common ground that international human rights law lays down the basic principles that should be implemented while addressing climate migration (Crépeau 2012). A new treaty could play an important role in setting the agenda or advocating for domestic policies, but "soft law" instruments (like a resolution of the UN Human Rights Council or of the UN General Assembly) could play the same role without requiring the long and difficult process of signature and ratification by states (Mayer 2011). Indeed, the "Nansen initiative towards a protection agenda for people displaced across borders due to natural disasters and the adverse effects of climate change," established by a few states in October 2012 as a consultative process, may be taking the direction of promoting some sort of guiding principles on disaster-induced migration (Kälin 2012).

While the adoption of such instruments may be promising, a word of caution is necessary. As explained above, the concept of "climate migration" is essentially arbitrary. Following the rights narrative, it would be arbitrary to limit protection to migrants attributed to climate change, as the cause of migration should be indifferent, or to limit protection to migrants, as the most vulnerable are often unable to migrate. Following the responsibility narrative, the international community should certainly organize a form of reparation for states and individuals affected by climate change, but this reparation does not justify an interference with the way a state decides to adapt to climate change. There is something profoundly disturbing in the possibility that the international community may impose arbitrary humanitarian priorities upon developing countries. There would in particular be important costs of opportunity if scarce domestic resources were focused on climate migrants rather than being more equitably distributed among all of those who need assistance within the state (migrants and nonmigrants), or if these resources were all diverted to address present humanitarian crises rather than dedicating some resources to promote long-term sustainable development and resilience to climate change.

The advocacy for international regulation often lies on two assumptions, according to which, firstly, the states affected are reluctant to protect climate migrants within their jurisdiction and, secondly, that international law can do something about it. Both assumptions are questionable. On the one hand, the need for protection of climate migrants often results from the lack of capacities rather than from the unwillingness of a state to protect its population. It must be kept in mind that the impacts of climate change in developing states such as the Maldives, Bangladesh, and Nigeria do not only affect individuals: they considerably diminish the capacities of states, some of which already face many other severe issues such as poverty, violence, and corruption. On the other hand, it is also uncertain that international law can curb the conduct of those states that are able but unwilling to act in a certain way. There is no direct way to enforce international law (like police does in domestic contexts). The international trade sanctions that are often used against pariah states affect the population more than their leaders. In any case, a treaty only obligates those states that have decided to ratify it. Most of the norms that an instrument on the protection of climate migrants would contain are already norms of international law, and simply rehearsing those norms will not automatically lead to a change of conduct, although it may contribute to different political, social, and cultural processes through which the international community influences domestic politics.

Rather than international regulation, attention should be given to institutional governance as a possible element to promote international cooperation with regard to climate migration and other forms of migration. In the many states that show willingness but are unable to provide protection, cooperation is essential to supplement the capacities that a country needs, among others, through international assistance and capacity building. In those other countries that would be able but are unwilling to comply with their obligations, international socialization would help to prompt compliance. Rather than state-to-state discussions, an international organization would provide a greater authority as a unique voice, relatively independent from global day-to-day politics, established on a solid expertise.

Therefore, perhaps the most worrisome issue raised by the debate on climate migration is the absence of an international institution with a specific mandate of protecting migrants. On the one hand, the UN High Commissioner for Refugees, which is the "UN refugee agency," has developed significant expertise on assistance and protection, but its mandate is narrowly conceived. The agency's initial focus on refugees has been extended to other persons of concern, such as stateless persons, returnees, asylum seekers, and some internally displaced persons, and it has provided some assistance in responding to natural disasters. Yet the UNHCR has no general mandate covering generally all migrants or climate migrants. On the other hand, the International Organization for Migration (IOM) is a self-standing international organization, outside of the United Nations system, which has significantly expanded its membership since the end of the Cold War, reaching 155 parties in January 2014, but has no proper protection mandate. The IOM provides logistical assistance as requested by states, for instance with regard to the control of migration and to the recruitment, transfer, and voluntary return of migrants. As the UN Special Rapporteur on the Human Rights of Migrants recently noted, "the mandate and funding of IOM pose structural problems with regard to fully adopting a human rights framework for its work: both would need to be revised if the organization is to become a key player in the promotion and protection of the human rights of migrants" (Crépeau 2013). The Special Rapporteur considered new institutional arrangements, such as a new UN agency, the expansion of the mandate of the

UNHCR or the transformation of that of the IOM, or, on a shorter term, a set of measures to strengthen the current institutional framework such as through increasing the frequency of High-Level Dialogues on Migration and Development within the UN General Assembly. Such options suggest relevant responses to many of the questions raised by the debate on climate migration.

Other institutional questions relate to the ability of today's international institutions to channel efficient international funding to support development and capacity building, in particular in countries affected by climate change. Important discussions are ongoing, within the climate regime, on international funding for climate change adaptation as well as loss and damage mechanisms that may support countries affected by climate change. The voluntary nature of states' contributions and the limited amounts proposed so far fail however to respond to the constant calls for the responsibility of greenhouse gas emitters.

Conclusion

Social progress rarely comes straightforwardly from fully reasoned ethical arguments. Rather, biased representation and emotions are some of the factors that allow the success of certain arguments instead of others in public deliberation (Crawford 2006). That the concept of climate migration is essentially flawed and virtually impossible to implement should accordingly not be the end of our discussion: because of its ability to generate momentum for change, the concept appears as a rare opportunity for meaningful progress toward fairer international governance. The refugee regime succeeded in the post-Second World War, thanks to its ability to reconcile individuals' rights with states' "enlightened self-interests" (Hathaway 2005), thus fostering an important step toward what was to become international human rights law.

The concept of climate migration is a powerful one as it calls to two of our deepest contemporary fears: climate change and migration. Doing nothing in front of such fears is politically impossible, while granting an individual status to "climate migrants" is practically impossible. It belongs to us to foster advocacy and create institutions that are able to direct the momentum for change toward meaningful progress toward the protection of the rights of migrants and the responsibility of greenhouse gas emitters. There are major risks, however, that such fears may rather fuel xenophobia and tense the relations between developed and developing countries or at least impose inappropriate policy priorities on resource-constrained states.

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Climbing the Adaptation Planning Ladder: Barriers and Enablers in Municipal Planning

Elisabeth Hamin and Nicole Gurran

Contents

Abstract

Local municipal governments have a crucial role in helping communities adapt to climate change. Recognizing different levels of climate preparedness, this chapter analyzes what steps communities tend to follow when they move forward on climate adaptation, including prerequisites for planning and the selection of policies. Drawing on content analyses of local climate adaptation plans from the USA and Australia, as well as interviews with municipal planners

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in both nations, the chapter explores the adaptation policy choices communities are making and explains the range of strategies local governments have used to move forward on a "ladder" of climate adaptation, proceeding from awareness and constituency building activities through formal risk analyses and strategic planning for climate adaptation, through implementation through specific changes to land-use planning and infrastructure investment. Factors found to support or hinder these efforts relate to political will, staff resources, technical information, and training in potential policy responses. Significant barriers include issues of property rights and sunk investment in vulnerable locations (particularly along the coast), as well as shifting community and political views about the reality of climate change. Overall, progress in municipal climate adaptation planning is patchy and affected by wider policy frameworks and access to state- or national-level support. However, this chapter highlights opportunities for municipalities to move forward on climate adaption planning, despite local barriers to action.

Keywords

Municipal responses • Adaptation barriers • Local planning

Introduction

Adapting to climate change is, in many ways, a local issue. The interaction of climate with specific local geographies and populations means that each place has unique issues and opportunities, and planning to increase resilience has to occur at this local level to accommodate that variability. Improving local governance, infrastructure, and built form in urban areas provides great potential to increase the safety of the world's majority-urban population while improving quality of life. However, urban policy frameworks and technical expertise among planning practitioners remain in a state of evolution, two decades since the passage of the United Nations Framework Convention on Climate Change (1992). Early urban policy action focused on reducing greenhouse gas emissions through policies to limit sprawl and reliance on private automobiles and to shift patterns of energy use in the built environment – termed "mitigation planning." "Adaptation" approaches have the goal of reducing the vulnerability of communities and the built and natural environment to the impacts of now-unavoidable climate change. Appropriately, in developed countries, the first attention went to mitigation, and only recently has there been much uptake of local policies for adaptation. Research on climate change adaptation (CCA) planning emphasizes a number of barriers impeding local response, such as insufficient data on potential climate risks, a lack of political will to change, and a lack of state- or national-level mandate for action. Nevertheless, some communities have made important progress in addressing climate risk within their local planning frameworks.

Organized local action on climate change really commenced with the implementation of *Local Agenda* 21 (LA21), a set of commitments for local engagement in sustainability planning, agreed by municipalities from throughout the world, at the 1992 United Nations meeting just described. At the subsequent 2002 World

Summit held in Johannesburg, emphasis moved more explicitly to local sustainability "action." Since this time, climate change has become an increasing theme in local environmental initiatives. The Cities for Climate Protection (CCP) campaign, spearheaded by ICLEI, has resourced and encouraged many of the municipal actions around greenhouse gas reduction, with more than 1,000 cities, towns, counties, and associations' worldwide members of ICLEI by 2013 (ICLEI: Local Governments for Sustainability 2014). However, overall, municipal actions have related to climate change mitigation, rather than adaptation (Measham et al. 2011; Castán Broto and Bulkeley 2013).

Many of the world's global cities, particularly within the developed world, have demonstrated significant leadership, with cities such as London, New York, Amsterdam, and Sydney all developing landmark plans and programs across a spectrum of carbon reduction and climate adaption approaches, particularly in relation to energy, water, waste, and, increasingly, risk reduction planning (EEA 2012). However, smaller municipalities and those in the global south have made more varied progress, particularly in relation to considering potential increased climate risk within their land-use planning framework (Baker et al. 2012; Carmin et al. 2012; Romero-Lankao 2012; Bierbaum et al. 2013). Given that the effects of climate change seem to be consistently "ahead of schedule" (Betts et al. 2011; McKibben 2011) and the long-time horizon for built form to change in response to changes in policies and plans, this is a significant problem.

To give a sense of what sorts of actions are possible at the municipal level, the chapter begins by identifying the policies and practices that first-adopter communities are undertaking. Following that, the chapter focuses in on the process that these communities are using to reach those policies and the conditions and actions that enable or disable progress particularly in relation to land-use planning for climate adaptation. The empirical data suggests that the steps undertaken by communities lie along an adaptation "ladder." In conclusion, policy interventions and other forms of support needed to help local communities move forward on the adaptation ladder are proposed.

Research Method

Three empirical studies of adaptation practice by the authors, plus insights from the research and practice literature, are synthesized to inform this chapter. Hamin and Gurran (2011) examined the small number of climate change adaptation plans that had been prepared by communities as early as 2010, comparing practice in two nations – the USA and Australia, which both have similar governance and land-use planning systems. Both nations have three-tier federal, state, and local governments, with planning law defined by the states but implemented by municipalities who show varying levels of heterogeneity in their policy approaches and priorities. This means that even when strong state policy exists, very different local planning frameworks and outcomes are typical in both nations. We identified stand-alone climate adaptation plans and separate adaptation chapters in wider municipal documents from two sources. One was the American Planning Association's (APA) list of cities and towns that had undertaken climate planning (APA's Green Communities Research Center 2010); the second was Australia's local government database Commonwealth Government's Local Adaptation Pathways Program, which provided financial support for local adaptation between 2009 and 2011. Despite this wide net, only eight municipalities were identified to have full adaptation plans in place or exhibited drafts with specific spatial or land-use policies as of November 2010. Each climate plan was analyzed in relation to climate threats and impacts, key goals and recommendations, and the relationship between the adaptation plan and other local climate change mitigation strategies or plans. The analysis provided a suite of local options for addressing climate change in municipal planning, as discussed below.

Two next-phase studies sought to understand the issues and barriers facing other municipalities, and steps taken to move forward. Primary research was carried out in Australian coastal councils between 2010 and 2011 (Gurran et al. 2012a) and in coastal Massachusetts of the USA between 2011 and 2012 (Hamin and Gurran 2013). The focus on coastal locations reflects the particular issues arising from climate risk in coastal areas, and the likelihood that community sentiment toward climate risk is heightened in these contexts, thus providing an important political impetus for action. For Gurran et al. (2012a), 55 local government areas (just under 10 % of Australia's total local municipalities) were surveyed, representing coastal areas with identified common issues arising from population growth and change, inadequate or declining infrastructure, and economic instability. The companion study undertaken in coastal Massachusetts in the USA involved 15 interviews with 15 cities and towns, conducted in 2011. The results presented below represent a synthesis of the findings of these three studies as well as the broader literature.

Climate Change, Spatial Planning, and Municipal Action

Planning Processes

The impacts of climate change are already being observed many parts of the world, as documented elsewhere in this book. Rising temperatures, more frequent and intense heat waves, water shortages, rain events, and changes in the spatial range of bushfire risk all have implications for the siting and design of new development and for the ongoing utility of existing homes and infrastructure. Global sea level rise represents a particular threat to coastal ecosystems and settlements. Social and economic implications of increased climate changes are also significant and will vary across geographic areas and community groups. In the major cities, hotter temperatures and more frequent storms or flooding cause major disruption due to the density of people and major infrastructure affected. However, in many regional areas, drought, inundation, and storm events can ravage the economic base of small settlements, while providing or restoring services and infrastructure to rural and isolated communities can be much more difficult (IPCC 2012).

Although future impacts of climate change are uncertain, decisions regarding settlement patterns and building design will have lasting impacts – with most buildings and infrastructure designed to a 50–70-year life span. Current planning frameworks must neither exacerbate contributions to greenhouse gas emissions nor increase community exposure to climate threats (Hamin 2011). Rather, strategic planning decisions should actively facilitate climate change mitigation and adaptation opportunities. Overall then, climate change represents multifaceted challenges for spatial planning – the decision-making framework governing the location and design of development and infrastructure. Given that climate impacts will differ markedly between places, local planning is particularly important.

The following principles have been identified to guide local planners in developing adaptation responses to climate change for their communities:

1. Adaptation energies should complement strategies for greenhouse gas reduction. Climate change mitigation should be seen as long range adaptation, and adaptation approaches that might increase carbon pollution or have other negative environmental effects should be avoided.
2. Secondly, because decisions about the built environment will have lasting impacts, planners must be ready now to prevent further risks associated with climate change and to support rapid adoption of new approaches if and when required (Gurran et al. 2008).
3. Social equity considerations in climate change adaptation are also important, and planners must recognize that vulnerability is not evenly spread across a community. Poorer and minority constituents are more likely to be located in geographically vulnerable areas to start with. As harms occur, less-resourced groups will tend to be disadvantaged by costs needed to cope with increased climate volatility and have less capacity to enact dwelling modifications for climate safety or comfort.
4. In deciding whether or not to move forward, it is worth prioritizing actions with multiple benefits for the environment or community (like enhancing natural ecosystems to improve resilience to climate impacts, or providing more opportunities for non-motorized transport) (Gurran et al. 2012a).

It is important to recognize that the techniques and processes of planning practice must also respond to new pressures and challenges associated with climate change. Traditional planning practice draws heavily on research and data based on past trends and generally assumes a stable framework of a predictable future. However, unpredictability is one of the major challenges associated with climate change. Faced with uncertainty as to the timing, nature, and magnitude of risks, planning needs to include adaptive management, where decision and response frameworks are designed to adjust to changing circumstances and information. Such approaches can be designed into statutory planning documents through controls that are triggered when a particular "threshold" is reached or when new information comes to light (Folke 2006; Abunaser et al. 2013). A second approach is that of scenario building, whereby potential story lines about the future are developed as a way of exploring or testing different possible approaches in a more creative way (Wilson 2009).

One of the major differences between local climate mitigation strategies and the commencement of adaptation efforts is the need to understand potential local climate change risk. Climate vulnerability assessments generally provide the basis for informing strategic land-use planning decisions on levels of risk in relation to an entire local area, site, or development proposal (National Research Council 2010). In drafting planning instruments and criteria for development assessment, existing information used to support land-use planning decisions – including floodplain and bushfire protection thresholds or models – may need updating or reconsideration over time as new data becomes available, particularly in relation to likely increases in the intensity or frequency of these events and projected new geographical range. It may be necessary to reorient natural hazard assessment methodologies from historical events to forecasted impacts associated with climate change scenarios.

Policy Responses

There are quite a variety of possible policies to respond to climate change at the municipal level. As noted above, all policies should seek to achieve dual goals to adapt to climate change impacts and promote long-term mitigation (reductions) of greenhouse gas emissions. Infrastructure examples include establishing new, decentralized energy, water, or waste management plants that reduce the carbon impact of settlements while contributing to resilience of the entire network in case of natural hazards. Self-provision of distributed and smaller-scale key infrastructure services – like energy, water, and waste management, through technologies for micro-energy generation, water retention, reduction technologies, and waste minimization, reuse, and recycling – tends to create a more disaster-resilient community. Part of resilience is assuring that new facilities can be retrofitted for more sustainable technologies as they become financially feasible. For instance, solar access should be protected to ensure future capacity for onsite solar generation. Regulatory burdens to require proposals for renewable energy infrastructure should be minimized, and where possible, the planning policy should be shifted to favor renewable energy projects (Department of Communities and Local Government (DCLG) 2007).

Similarly, there are a number of basic approaches to reducing the carbon impact of transportation systems and improving resilience to future climate impacts and potential oil scarcity. New and existing settlements should be designed or reconfigured to reduce trip generation and to encourage public transport use and active transportation such as walking and cycling. Safe, naturally vegetated walkways and cycle paths should connect residential, retail, employment, and recreational areas. Proposals for new development should include travel plans which include a range of sustainable transport options – walking, cycling, public transport, and only lastly the private motor car (Newman et al. 2009).

Urban design guidelines and building codes for public and private buildings should be designed for future climate scenarios. While much has been written about sea level rise, addressing potential urban heat island effects arising from hotter temperature and heat waves is also an important consideration when preparing urban design guidelines and assessing public and private buildings in built-up areas (Stone 2012). Requirements for urban vegetation, "green" (planted) roofs, and specific colors for building and paving materials can be considered. Public space designs must anticipate more severe local climatic conditions, with shading, shelter, and appropriate vegetation to cool areas of open space and walkways or cycle paths, as well as designing public amenities for safety and storage during disaster events.

In planning for areas where risk is found to be high, decisions fall roughly into three categories: to protect infrastructure through engineered fortification, such as a sea wall; to accommodate threat through planning and design modifications; or to retreat, by relocating infrastructure and activities. Such decisions often need to be made at a local scale, responding and adapting to specific circumstances as they unfold (de Vries and Wolsink 2009). In planning for new settlements, or for new development within existing areas, it is important to reserve space for emergency access, congregation, shelter, and evacuation. In particularly vulnerable areas, locations for intermediate post-emergency recovery, such as temporary housing, should be identified. Long-term planning ensures that intermediate land-use decisions do not compromise future opportunities (Meck and Schwab 2005).

Climate Adaptation Plans: Policies Actually Chosen

The literature described above outlines potential policies for CCA. But what steps are communities actually choosing? Table 1 identifies the actions taken by eight early-adopting communities in Australia and in the USA who prepared specific plans for adaptation.

As shown in Table 1, the full suite of potential policy responses is being attempted across the plans reviewed, although not necessarily within the one local area. The most comprehensive adaptation planning frameworks (for instance, plans for Keene, Olympia, and King County in the USA and Brisbane and the Gold and Sunshine coasts in Australia) cover land-use allocation, development and design controls, infrastructure provision, urban transport, and even the ongoing resilience of food supplies. By contrast, more targeted frameworks focus more on direct climate risks (e.g., Chicago, Hornsby, Melbourne, Mandurah).

Climbing the Adaptation Ladder

As the literature has progressed, a general perspective on the process of adaptation has emerged. Moser and Eckstrom (2010) suggest that adaptation occurs in these phases:

Table 1 Policies recommended in climate adaptation plans, USA and Australia (Adapted from Hamin and Gurran 2011)

Local authority	Plan name	State	Population category	Location	Key land-use planning actions
Keene	Adapting to Climate Change: Planning A Resilient Community 2007	New Hampshire	0–50 K	Inland	Scientific staff to provide climate change information to policymakers for consideration in regulation and decisions; review comprehensive plan; hazard mitigation; and relevant building ordinances/design standards in light of potential climate change impacts; create flood control zone; protect and rehabilitate historic and cultural resources to reduce vulnerability; code and plan revisions for water quality protection
Olympia	Olympia's Response to the Challenge of Climate Change 2007	Washington	0–50 K	Inland	Develop new sustainability design standards (green building materials, energy conservation principles); design standards for greater resilience to severe weather, floodplain identification; identify alternative route options for movements of goods and people; sustainable transportation mode choices; promote locally generated; secure energy sources; increase protection of existing/future wetlands to enhance resilience of ecology and hydrology; increase water-storage capacity; increase food security – identifying and protecting prime agricultural soils
Berkeley	Berkeley Climate Action Plan 2009	California	50–300 k	Coastal	Encourage water efficiency; expand and diversify water supply; increase urban tree cover
Chicago	Chicago Climate Action Plan 2008, Especially Chapter 5: Adaptation	Illinois	1–3 M	Inland	Refers to previous efforts in encouraging denser less car dependent development; introduction of stormwater regulations
King County	King County Climate Plan 2007, Especially Section 6B On Adaptation	Washington	1–3 M	Inland	Update heat response plan – research into urban heat island effect; encouragements for innovative cooling/energy efficiency in properties; "Green Urban Design Plan" (permeable pavements; rooftop gardens; green alleys; onsite mechanisms to prevent flooding); amendment of landscape ordinance for climate tolerant plants

Hornsby	Climate Change Adaptation Strategic Plan 2009	New South Wales	50–300 K	Coastal	Review planning controls to strengthen requirements in locations of increased vulnerability
Gold Coast	Gold Coast Climate Strategy 2009	Queensland	300 K–1 M	Coastal	Designate climate sinks in local planning scheme; scope local food production opportunities and requirements; implement coastal planning measures
Sunshine Coast	Sunshine Coast Climate Change and Peak Oil Strategy 2010	Queensland	300 K–1 M	Coastal	Revised sea level rise projections; planning controls to improve resilience of natural systems; risk assessments in planning decisions; planning controls to encourage localization
Brisbane	Brisbane's Plan for Action on Climate Change and Energy 2007	Queensland	1–3 M	Inland	Planning controls to prevent flood/storm surge exposure; shade and weather protection; transit-oriented development to reduce emissions; reducing barriers to urban food production; improve resilience of natural systems – no net loss of natural vegetation
Darebin	Climate Change and Peak Oil Adaptation Plan 2009	Victoria	0–50 K	Inland	Zoning flexibility – provision for local food production; assessing planning controls to remove impediments to resilience strategies; appropriate development in areas subject to climate risks
Melbourne	Climate Change Adaptation Strategy 2009	Victoria	0–50 K	Coastal	Revised planning controls for sea level rise; new building standards to manage heat island effect
City of Port Phillip	Draft Climate Adaptation Plan 2010	Victoria	0–50 K	Coastal	Revise planning controls to restrict building in areas of coastal vulnerability; require climate adaptive building design and vulnerability to be considered in planning decisions; amend planning controls and permit requirements accordingly
Mandurah	Coastal Zone Climate Change Risk Assessment and Adaptation Plan 2009	Western Australia	0–50 K	Coastal	Modifying planning process; amending standards; reviewing information requirements for decision-making

- Understanding the problem (detect the problem, gather and use information, re-/define problem)
- Planning phase (develop options, assess options)
- Managing stage (implement options, monitor outcomes and environment, evaluate effectiveness of option) (see also Arnell and Delaney 2006; National Research Council 2010)

This of course mirrors the general comprehensive planning process. One key difference is that built into the "understanding the problem" phase are forecasts of climate change and analysis of who and where is most vulnerable to those changes.

More precisely, our empirical research suggests a continuum of stages in developing climate adaptation responses within local areas, beginning with risk analysis moving through the preparation of an adaptation strategy to changing planning controls. This pattern is consistent with previous research identifying a climate risk analysis as a precondition for further adaptation action in Australian public and private sector organizations (Gardner et al. 2010). This risk analysis informs the development of a framework for strategic adaptation action across the many responsibilities of local government and might include actions ranging from community education through to developing applications for external funding and resources.

With a risk analysis in place, communities' next typical step was to change the planning and regulatory framework governing future development, so that such development enhances resilience to climate risks, rather than furthering exposure. Subsequent actions involve rethinking the ways in which local infrastructure (both public and private) is designed and delivered, before finally establishing a funding strategy to resource ongoing intervention. These last two stages have as yet been undertaken by only a few of the municipalities or councils involved in our study, but the vast majority of responding agencies indicated that they intended to commence such work in the near future. In doing so, a strong evidence base will be needed with detailed local-level information, including costings on necessary adaptation expenses over time. Strategic assistance to help councils overcome barriers to the adoption of more resilient forms of infrastructure design and delivery will also be needed. Note that the actions above are being taken in regard to new development permits and infrastructure. The literature may suggest substantial changes to existing property such as retreat, but that is much harder to accomplish for obvious reasons. Absent a major loss or disaster, our survey respondents were not attempting to force change to existing properties.

Taken together, these series of actions suggest a ladder of adaptation that communities are tending to follow, at least in coastal Australia (Fig. 1).

The ladder begins with institutional awareness of climate change issues through to developing an information base (risk analysis) and to preparing an umbrella framework for adaptation action. Subsequent implementation stages typically include amendments to land-use planning controls and, finally, investment in infrastructure augmentation or change (see also Tompkins et al. 2010). Although regulatory change itself is time-consuming and costly, involving consultant studies, legal opinions, local

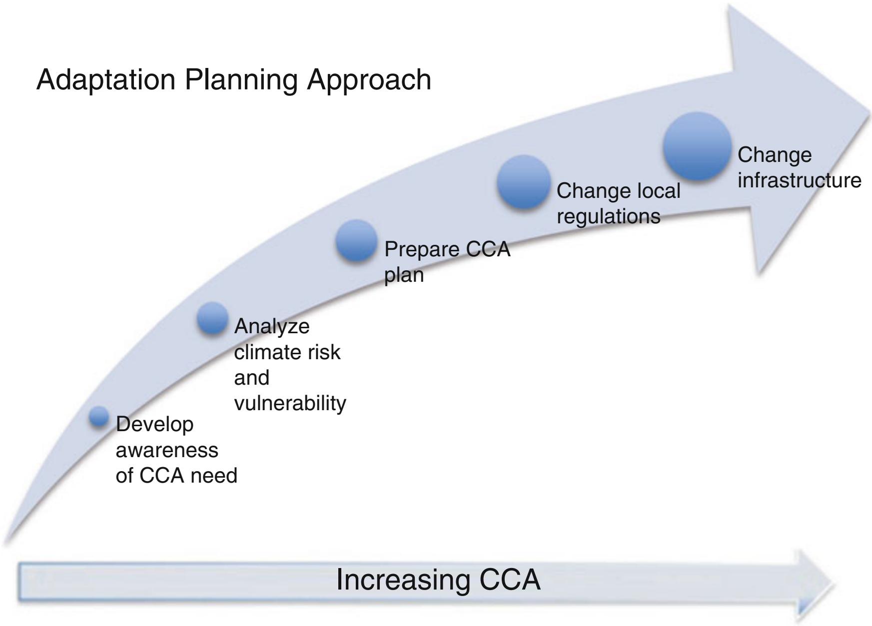

Fig. 1 Adaptation ladder (Adapted from Gurran et al. 2012b)

politics, and potentially, litigation, these costs are far less than those anticipated for key municipal infrastructure upgrade or relocation. Retrospective adaptation action for existing infrastructure will likely be delayed until the infrastructure requires replacement, resources are available, and/or the risk becomes quite urgent.

Barriers to Adaptation Action

The sections above have identified what typical actions are and the steps through which communities tend to move. This section discusses the process itself – what has enabled governments to move forward, what tends to slow them down, and the processes that are most appropriate.

Barriers can cover a wide range of issues, but, following Adger (2009), they are socially constructed and thus not insurmountable. Moser and Ekstrom (2010), building from the wide range of research identifying barriers to adaptation planning (Mukheibir and Ziervogel 2007; Amundsen et al. 2010; Nielsen and Reenberg 2010; Measham et al. 2011; Mozumder et al. 2011; Rosenzweig et al. 2011), explain the necessary conditions for CCA as the following:

- *Leadership*, whether in the government or grassroots-level activism. Leadership is particularly essential when there is no regulatory mandate or local public demand for action.

- *Resources*, including technical information such as regional climate forecasts as well as staff time and expertise.
- *Communication and information* , which is particularly understood to be public participation and the flow of communication among those responsible for action; there is a sense in the article that this is a top-down flow of information from agencies to the public as well as cross-flow among members engaged in a CCA planning process. Note that in this formation, technical information needs are included in the resources category above.
- *Values and beliefs*, especially regarding risk and how it should be managed and what concerns have standing. Although not explicit in the original framework, for our purposes, belief (or lack thereof) in the anthropogenic causes of climate change would be categorized here (Moser and Ekstrom 2010; Hamin and Gurran 2013).

Adaptation barriers thus arise when deficiencies across any of these elements occur during any stage of the adaptation planning process. For instance, Arnell and Delaney (2006) characterize barriers in relation to *missing operators*, arising from a lack of awareness by leadership of the need for adaptation, and *missing means* – that is, limited institutional capacity, budgetary constraints, and lack of regulatory authority (see also Gupta et al. 2010; Berkhout 2012). They also point to the problem of *unemployed means*, where because of misallocation of costs and benefits, actions are not taken. A relevant example would be homeowners not moving because low-priced nationally subsidized flood insurance will reimburse their losses or local government officials prioritizing other budgetary items – such as short-term infrastructure upgrading (Measham et al. 2011).

Empirical studies generally support these theoretical frameworks. Among the most basic needs are climate change awareness and technical knowledge of how to proceed; Australian research has found that planners express uncertainty about how to begin CCA planning, despite evident awareness and conviction about the need for action (Measham et al. 2011; Baker et al. 2012; Gurran et al. 2012a). Consistently, if regulatory authority or mandates to support adaptation efforts are absent, it is much more difficult for planners overcome local barriers arising from insufficient information and capacity constraints (Few et al. 2007; Funfgeld 2010; Tang et al. 2010). State mandates, while sometimes viewed by local officials as intrusive and controlling without the benefit of additional funding, can provide both an alignment of values and the political cover needed when facing opposition from constituents (Bedsworth and Hanak 2010; Dalton and Burby 1994). Guidance from the state or region should present the best available science in order to influence beliefs while considering financial compensation to constituents adversely affected by the policies (Bedsworth and Hanak 2010). By implication, a state mandate would overcome concerns about the legal basis for changing zones or ordinances in relation to climate adaptation. For other activities, such as provision of water infrastructure, specific state regulations need to change for local authorities to modify their own systems.

Previous research and policy development work has emphasized the importance of access to additional resources in helping local governments build capacity for climate change adaptation, particularly in local government areas already struggling with resource constraints (Baker et al. 2012; Bierbaum et al. 2013). This is similar to many topics – a study of 100 cities in California's Central Valley found a link between the cities' fiscal means and the occurrence of sustainability policies (Lubell et al. 2009). In well-resourced communities, addressing barriers tends to be more an issue of facilitating effective use of resources rather than a need to create capacity per se (Burch 2010). But this requires political leadership to push adaptation to the top of the priority list. As Measham et al. (2011) have suggested, because climate change adaptation is not embedded within local planning practice, it is easily displaced by the context of routine demands.

Case Study: Barriers to Action in Massachusetts Coastal Communities

To ground this discussion of barriers and enablers of CCA, it may be helpful to provide two case studies, one focusing on what prevents forward movement and one on what enables it. These are of course closely interrelated, but not exact mirror opposites.

In Massachusetts, cities and towns update their master (comprehensive) plans when they wish to – there is no legal requirement for updates. There is no state or national mandate or funding for CCA; there are not even any accepted projections for climate change upon which towns can rely. Consequently, local CCA planning can only happen through very conscious effort to undergo dedicated CCA planning process, or if a town happens to be updating their master plan. Unsurprisingly, forward movement on adaptation at the local level has been quite slow. In reviewing all 351 cities and towns of the Commonwealth, only Boston had prepared a dedicated CCA plan as of 2012. One town is including a CCA chapter in their new master plan, which is now underway. Despite this, most of the planners in our 15 case study communities saw value in including CCA in their comprehensive or capital improvement plans. Many of the responses resonate with previous research: the three most common barriers to taking action reported were resources (staff and money), the sense that climate projections or climate science remains uncertain, and concern over politics or lack of leadership (Hamin and Gurran 2013).

Less reported previously is the impact of high private property values in motivating opposition to policy changes involving retreat options and in stimulating pressure to enable hard shoreline defense. After this, a range of barriers are mentioned: challenges from existing land-use patterns (which limit adaptation options), lack of public support or contrary local values, and the distant time frame of adaptive need. Various institutional constraints were occasionally mentioned: the lack of regional planning in the state, the lack of federal or state mandates for action, and difficulty in finding a legal basis for including adaptation in regulations. Planners also reported political unwillingness to threaten property interests in expensive coastal land. In coastal Massachusetts as well as many beach areas, the residents most likely to be affected by sea change policies tend to be quite wealthy and have the ability to concentrate resources to prevent change they consider undesirable (Hamin and Gurran 2013). This is evident in the Australian case study as well, discussed below.

Case Study: Planning, Property Values, and Community "Pushback" in Australia

Local values can provide an atmosphere of support for climate change adaptation or, alternately, can act as a barrier to that process (Wolf et al. 2013). The politics of risk are a major concern for Australian local governments. Councils that had reasonable success in making general plans for adaptation found it much harder to move to implementing regulatory policy (Gurran et al. 2012b). Vague comments regarding the need to adapt are one thing; plans and regulations that identify the affected properties are quite another. It did not seem to make much difference whether the property owner was a long-term owner or a "wash-ashore" who was just thinking about buying land. Several participants described pressure from affluent newcomers who had purchased sites in vulnerable locations and now sought to secure approval for new development, despite climate risk. These conflicting pressures arising from various stakeholder groups are a major concern for local councilors and professional staff. Respondents described a growing community "pushback" against climate change, driven by concern that identifying areas of climate risk and imposing exposure-reducing development controls would lower private property values, that has strong potential to erode local political support for adaptation measures. Given that the benefits of adaptation occur in the distant and uncertain future and that there is no obvious constituency for adaptation action, it has proven difficult even for local communities that started a solid CCA process with state funding to move into the implementation stage. The public – and often the planners – perceives climate change as part of the distant future, and it is difficult to care about that when there are pressing issues at hand.

Overcoming Barriers Through Alternative Processes

In general, the literature and discussions on climate adaptation tend to propose two basic approaches to forward movement of CCA policies. The first is overt adaptation planning (Adger et al. 2005), in which the city or town prepares a comprehensive strategic framework based on climate forecasts and vulnerability analyses. The advantages here include the comprehensive nature of the method, which should assist in preventing maladaptation, the ability to include the public through regular participatory processes, and having as one product of the process an agreed-upon climate projection or set of scenarios (Preston et al. 2011). It appears that the comprehensive planning approach may overcome several barriers: it provides the ability to request resources for CCA, to develop an accepted climate projection for use in guiding policy, and to generate public support through participatory processes.

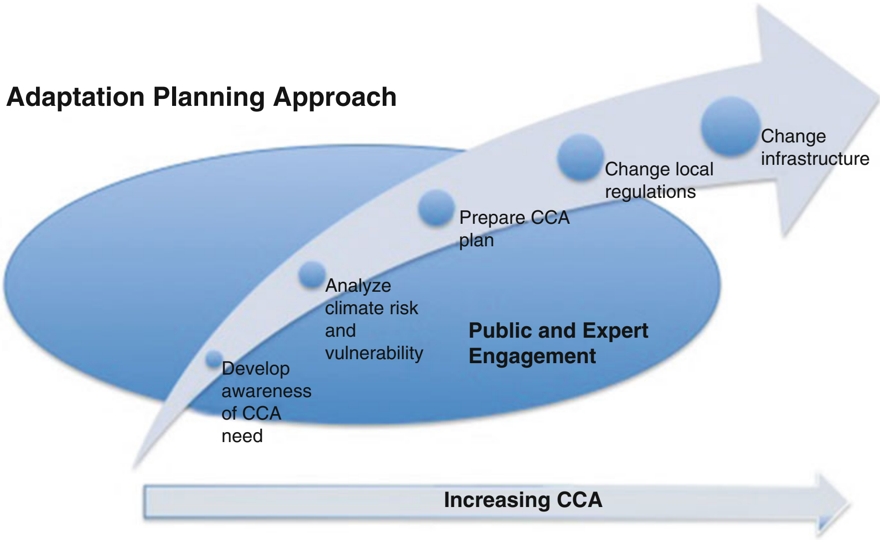

Fig. 2 CCA planning approach

Figure 2 reprises the ladder of adaptation as a planning process, with a focus on the potential to engage the public throughout many steps of the process, thereby bringing in better transparency and potentially building political support.

The second approach is often termed “mainstreaming” and implies moving directly from climate forecast to changing technical specifications and regulations without going through a full, stand-alone climate planning process (Klein et al. 2005; Sharma and Tomar 2010). In this approach, officials can avoid discussion with the public or formal planning processes and instead focus on changing regulations and technical specifications and including future climate as a normal variable in municipal management decisions. For example, at the urging of their regional planning body, several Massachusetts towns are including climate change projections in the vulnerability analyses for their, mandatory multi-hazard mitigation plans.

The advantages here include speed, as climate becomes a normal part of the municipal processes quite directly; implementation, as the goal is to bypass a long planning process and go directly to changing policy; and integration, as climate adaptation is situated within existing cross-sectoral plans and activities. The disadvantage is that there is little ability to engage the public and minimal ability to coordinate policies or undertake a proper risk analysis. Given this, mainstreaming may lead to more maladaptation over time, as there is little chance to consider action in its fuller environment or compare actions to assure they work together. But it does allow quicker forward movement and may be a good response when the issues are primarily technical, when upper-level political support is weak but department-level support is strong, or when too much publicity is likely to lead to community pushback. The general steps are demonstrated in Fig. 3.

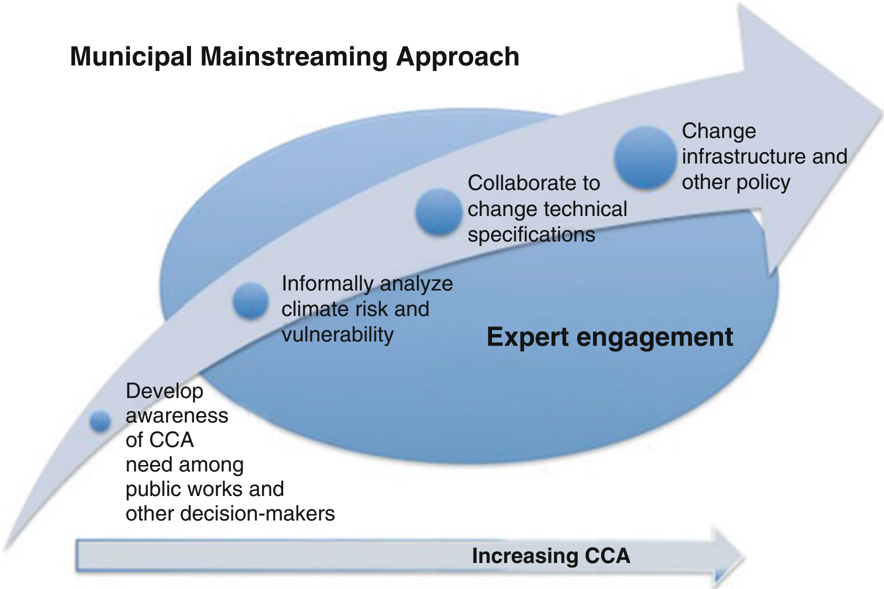

Fig. 3 Municipal mainstreaming approach

There is in addition a third potential approach which can be thought of as "stealth," but might be less controversially be described as the "no regrets + co-benefits, no discussion" approach. The idea here is to achieve some climate adaptation goals without identifying the actions as adaptation. Instead, the focus is on the other or "co-benefits" of a policy (United Nations Human Settlements Programme (UN-Habitat) 2011). Indeed, research suggests that at the national level at least, climate change is rarely the primary or stated motivation for adaptive action (Berrang-Ford et al. 2011), but the extent of incorporation of climate adaptation measures within other policy frameworks is largely unknown. With anticipated increases in sea level, floods, and stormwater intrusion (Frumhoff et al. 2007), most planners know there is pressing need for policy, but remain largely unable to publically frame the problem as one of climate change (Ruth and Coelho 2007). It may even be that adaptation actions situated within established policy areas, such as natural hazards frameworks, are more likely to endure changing political cycles (Gurran et al. 2012a). This approach had been used in the Australian context, with some local council professionals addressing skepticism by using a language of climate "variability" rather than climate "change," which they felt helped counter-act the growing political pushback against climate change. Even more so than mainstreaming, this approach lacks the advantages that a public process can bring and cannot achieve the perspective of a planning process. It works hit or miss. But in the hardest situations, it may be the way to start. Illustrative steps are identified in Fig. 4.

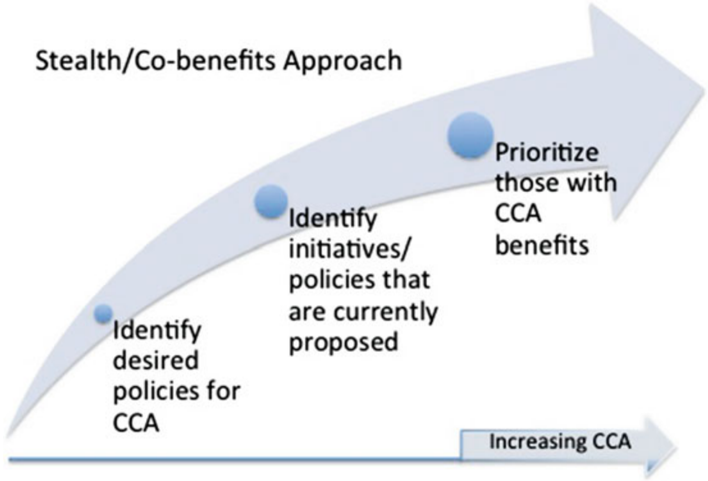

Fig. 4 Stealth approach

Choosing Your Approach/Overcoming Barriers and Engaging Enablers

The short story is, not surprisingly, that undertaking a proper plan enables engaging the public and thus can build political support and create long-lasting credibility. A plan can also assist in requests for funding and enable a more comprehensive view that may help in overcoming limits from lack of information and technical knowledge. Both the quality of the plan (clarity of goals, policies, and regulation (Neuman 1998)) and the quality of the process (participation, community education, and support (Baer 1997; Laurian et al. 2004; Burby 2003)) are important, and the plan can provide a bottom-up, participatory approach. Mainstreaming, in contrast, encourages the technical uptake and integration of CCA into a range of municipal decision-making, which can address important infrastructure issues such as how high a bridge should be, or how large a water reservoir may be needed under changed climate. But mainstreaming is unlikely to build political support. Both mainstreaming and stealth may be efficient in getting movement quickly – for instance, in assembling data and undertaking basic changes to local strategies, guidelines, and, perhaps, regulations, without inflaming climate change debate. However, stealth is unlikely to be able to move CCA very far along given the need to gain political support for increased expenditure, when actions need implementing, or for the exercise of unpopular decisions, both of which depend on leadership- and community-endorsed policy (Rosenzweig et al. 2011; Brody and Highfield 2005).

A logical approach then could engage all three: beginning with overt CCA builds constituency, mainstreaming achieves integration, and stealth is an option if political change threatens policy commitment. If politics are an initial barrier, start with a stealth approach, seeking co-benefits policies first while laying political ground work for a comprehensive CCA planning process and mainstreaming into a range of policies. Further work is needed to know whether, in the case of climate adaptation, an explicit process, including community engagement, delivers better outcomes (in which case actions by stealth are best used as a last resort) and whether explicit climate adaptation strategies are more, or less, effective than those incorporated within other frameworks ("mainstreaming"), over the long term. Then, there are the questions of ethics and process, which are conveniently ignored here but must be part of the considerations when actually selecting actions.

Conclusions: Connecting the Dots Between Barriers and Approaches

CCA action in the communities studied is at too early a phase for strong conclusions. But some strategies for overcoming typical barriers nevertheless emerge.

Even without a strong legal framework, local governments have the potential to embed climate change considerations across all aspects of strategic planning and development assessment, as well as their wider operational, environmental management, and natural hazard activities, as outlined in this chapter. The strategies for low carbon development, which emphasize local and decentralized approaches to food, energy, water, waste, and transportation and preserving and enhancing biodiversity and natural processes, provide a blueprint for the wider sustainable community agenda, emphasizing resilience not only to future climate impacts but also to many of the other economic and social challenges likely to arise during the twenty-first century.

Adaptation, by improving resilience to extreme events as well as the increasing hardships of climate, provides local benefits. But getting that message across requires overcoming the typically short time frame of politics and budgets and considering instead a longer investment that matches investments and built form to the climate that is to come, rather than climates past. Some cities and towns have taken a leadership role and undergone adaptation planning without significant support from upper government levels. However, having state support through an existing state-level adaptation plan appears a far more reliable way to encourage local governments to make local adaptation plans.

Ultimately, this analysis of early generation local adaptation planning suggests that more sophisticated and detailed policy and practice innovation is needed to allow municipalities to translate climate vulnerabilities into a concrete response framework, particularly in relation to land-use planning. That adaptation actions are arising within the context of larger mitigation planning efforts suggests strong potential for synergistic solutions to be devised. Nevertheless, when new information about likely sea levels, flooding, and fire risks comes to light, difficult decisions regarding land-based adaptation measures will be needed, potentially including identifying new areas as no-build zones. This implies a need for specific planning tools – such as planned retreat and transferrable development rights (enabling historical development entitlement to shift to more appropriate locations) – to provide a basis for offsetting some of the inevitable costs to individuals associated with such decisions. Vulnerability analyses need to become more common to assure that the least resourced are not the most affected. There is also a danger that in failing to clearly connect mitigation and adaptation decisions in new generation plans, misalignment may seep into the ellipsis. But as more examples, technical/policy guidance, and nongovernmental support become available, in part building from the experiences of these early adopters, it appears reasonable to expect adaptation planning to spread, particularly with more explicit state and federal encouragement.

Overall, there is an urgent need to move beyond vulnerability analysis and into implementation of adaptation action. While "global" cities have been able to move forward, smaller cities are falling behind. Aid agencies have tended to prioritize rapid mainstreaming, while planners and policymakers want a comprehensive analysis of the adaptation situation. The frameworks presented here could encourage a more place-sensitive approach that matches barriers to approaches, encourages a more *realpolitik* awareness of the local challenges of adaptation implementation, and thereby assists smaller cities in making on-the-ground progress in implementation.

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Designing an Adaptation Strategy in a Complex Socioecosystem: Case of Territorial Climate and Energy Plans in France

Stéphane La Branche

Contents

Abstract

Adaptation has become an obligatory part of larger Territorial Climate and Energy Plans, mandatory by law for all communities over 50,000 in France. This chapter first described these TCEPs and then analyzes the elaboration process of two different approaches for an adaptation strategy. The first one is incremental, sector specific in an urban setting, and tightly associated to urban planning in the city of Dijon. The other is holistic, multisectorial, and multi-issue, in a semi-urbanized area that includes agriculture, very high-tech production, valleys, and high mountain areas. We then offer an evaluation of both approaches, with respective strengths, weaknesses, and potentials.

Keywords

Adaptation policies • Strategy • Design • Formulation construction

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> Limits of survival are set by climate, those long drifts of change which a generation may fail to notice. And it is the extremes of climate which set the pattern. Lonely finite humans may observe climatic provinces, fluctuations of annual weather and occasionally may observe such things as ‘this is a colder year than I’ve ever known’. Such things are sensible. But humans are seldom alerted to the shifting average through a great span of years. And it is precisely in this alerting that humans learn how to survive. . .They must learn climate. (Frank Herbert 1976: 350)

For the first time in human history, even since the first great human revolution, the Neolithic, and then the sedentarization of the human species, not only are we facing a truly global crisis due to climate change (CC) and its impacts, but more importantly, for the first time, we are *aware* of this crisis and are trying consciously to create planned solutions and apply them. This can be termed climate energy governance, or even meta-governance. But we have never attempted such an effort and thus have no real past experience to draw from. In the past few years, efforts at decreasing greenhouse gases – mitigation – have increased and improved in terms of efficiency and diversity. While much work remains to be done on mitigation measures, adaptation strategies to climate change are far from being as well understood and developed. Different countries have different methods, but to our knowledge, France remains unique in that adaptation is part of a legally binding territorial-level climate and energy package called Territorial Climate and Energy Territorial Plans (TCEPs).

Indeed, in 2012, the French central government imposed TCEPs on all communities or “community of communities” with over 50,000 people, attempting to implement national climate and energy governance measures at the territorial level, including both mitigation and adaptation measures. This followed several years of voluntary experimentations on the part of a few cities (Lyon, Grenoble, and Paris were leaders among them) starting in 2006 with Grenoble launching the country’s first territorial climate plan (a medium-size city of about 300,000 pop). Then, a national-wide multi-actor participatory procedure was conducted (the Grenelle de l’environnement), whose purpose was to design a national strategy related to energy, the environment, water, climate, and other related issues(?). The general conclusions of this multi-stakeholder process then led to a law project, linked to the Environmental Code. Several laws were indeed passed, but we focus on the now legally mandatory TCEP.

Three fundamental differences can be noted between the previous Plans and the new, binding, ones. First, previous ones were strictly voluntary. Efforts, experimentations, and measures were entirely left to the will of collectivities, with some state financial and expertise support. Second, these plans focused very strongly on the climate question and worked on the energy issue as a corollary of climate change. The new Plans put energy on the same level. And indeed, 2013 has seen a real turn with a strong focus on the energy dimension. Finally, the previously great ignored child of climate governance, adaptation, has become the third pillar of the new TCEPs.

One of the issues in this process is that the national-level efforts at designing a new national climate and energy governance remain on the level of a general strategy. Some actual exemplary measures and methods are proposed by the national administration, but these apply better to mitigation measures than to adaptation ones.

While mitigation policies are beginning to be well understood and tried, the "real," operational, adaptation policies still need to be designed and implemented, and even sometimes invented, at the territorial level. More than mitigation, adaptation is indeed a territorial-level, local, issue. As such, it is difficult to offer exemplary measures that would work on all territories. This explains in part why the national adaptation strategy guidelines and measures are so little consulted by local policy makers. They do not feel that these recommendations apply well to *their* territory and *their* local situation (both natural and socioeconomic and political).

The first part of this paper will quickly present some of the common points and differences between mitigation and adaptation policies in general. Then, we will analyze two case studies, focusing on adaptation: one city (Dijon) and a semi-urbanized rural and mountainous territory, the Gresivaudan Valley. Ambition and breadth vary but it is on the construction process of the adaptation strategy that we will focus on. Lessons for the operational dimensions of designing adaptation policy will then be drawn out.

One of the difficulties is that neither mitigation nor adaptation is sector specific: they are multi- and cross-sectorial. In addition, in France, TCEPs are supposed to give direction and a framework for other territorial planning documents: urban planning, mobility, housing, and other planning documents have to conform to TCEPs. This has direct consequences on agenda setting, institutional arrangement, and policy design, since traditionally separated sectors must now be harmonized toward general climate and energy goals. But adaptation presents additional challenges which I will expand on later.

Differences Between Mitigation and Adaptation for Policy Design

Mitigation aims at reducing GHG emitted on a territory and TCEPs give a clear numbered mitigation objective, the EU's 20 % reduction in GHG emissions, 20 % reduction in overall energy consumption, and 20 % renewable energy in the territorial energy structure, by 2020. Territorial policy design in the case of mitigation does not require anything really revolutionary. First, a carbon evaluation is undertaken – akin to the work and analyses preceding any type of policy. While the ADEME (a state energy and environmental agency) offers a method (which needs to be paid for), territorial collectivities may use any method deemed appropriate. The carbon analysis offers numbered data on emissions by sector, and thereby, a baseline from which to reach the 20/20/20 objective. In an urban setting, we find the same three main sources in France, but in different proportion, depending on the territory: transports, housing, and industry. In rural areas, of course, the agricultural sector takes more importance. There is no need to expand on mitigation measures here aside from a few precisions. In France (and this is akin to the rest of the world), mitigation measures are rather well known and well developed in the transport and housing sector (and by extension but to a lesser extent, urban management and land use) and do not represent much of an issue in terms of policy design. While the translation phase from policy formulation to implementation (e.g., the reduction of the share of car mobility and urban management – multifunctional polycentric, semi-dense urban development seems to be the general direction) still represents challenges (types of incitement, control, constraints, social acceptability, costs, training, etc.), the design phase of mitigation policies is "classical." Finally, while mitigation measures can be implemented immediately and be evaluated in the very short term (diminution of CO_2 emissions due to personal vehicles, number of buildings respecting energy consumption targets, etc.), adaptation requires a different approach. But before touching on this at the territorial level, it is important to remind why and how adaptation has been emerging in the last few years as an inescapable issue in climate governance.

Adaptation and Climate Change as Meta-risk

Climate change is now seen by the international scientific and institutional community as both the number one accelerator and amplifier of natural risks and the single most important obstacle to development efforts in the third world. In wealthy countries, it raises issues about the deep economic structure of our society and discussions about post-carbon or non-carbon-based production and consumption – or the green economy – emerging. In fact, the impacts of climate change and its origins linked to the very fundamental energy structure of our society mean that CC is slowly inserting themselves into every aspect of our societies. This also raises issues regarding the impacts of mitigation and adaptation efforts on other policies and on policy design itself. The underlying hypothesis that climate governance is *emerging* as a new type of *total* governance through four different means (La Branche 2013):

(i) It is inserting itself in the issue-specific or sector-specific governance (water, energy, security, housing, transports, research, development, public policies, health, economic development), as well as individual values and legal international, national, and local norms.
(ii) It tends to redefine these types of governance, *from above*, as an overarching framework.
(iii) It is also *diffusing through* sectors in a transversal (and multidisciplinary) manner.
(iv) It is emerging from below, from local actors, territorial communities, etc.

As such, climate and energy governance is emerging as a *meta*-governance that tends to restructure and redefine other forms and types of governance. In other words, it is increasingly offering a general framework and even a regime of truth in Foucault's sense (1980), in which policy design and implementation are taking place. Indeed, the challenge is total and global in the sense that it involves all human activities. In this sense, climate change is not only a phenomenon; it is an epiphenomenon (Olivier 2005), affecting the way we think and perceive the world as a globality.

Indeed, since 2006, climate and energy issues have been explicitly and increasingly integrated in different international programs and norms, such as the UN's Millennium Development Goals, water management and risks, insurance policies, construction norms, agriculture, local urbanism, etc. These are all slowly being redefined, reworked, reconceptualized, re-practiced, and even retaught in our teaching institutions with climate and energy objectives in mind. All these issues are both affected by the "objective" reality of CC and by the "subjective" efforts at dealing with it and managing it – i.e., governance. Our different field researches explore the impacts of efforts at climate governance on our institutions' structures, identities, strategies, policy formulation, and daily operations. This change does not occur without obstacles linked to a carbon-based path dependency (Pierson 2000) or to Young's arguments (2002a) regarding how an institution's structure and identity may prevent it from reaching its own environmental objectives.

Developing efficient and cogent adaptation strategies is thus framed by this emerging understanding of CC as a "meta-risk" (notion derived from Braithwaite and Williams 2001). My argument, derived from a social science framework of CC, puts forward that CC does not only amplify and modify existing risk, it also tends to modify our classical ways to manage and understand it. Not only does CC change the physical aspects of a risk, it also tends to redefine what is deemed to be a significant risk or not, "a risk that is worth trying to manage or not" because it may or may not increase vulnerability or decrease resilience. The objective of a climate adaptation strategy is not to adapt once the impact has taken place: it is to predict what the potential natural impacts might be in order then, to prepare for them before they happen, so as to reduce vulnerability and increase climate change resilience. But this depends greatly on social, organizational, cultural, and economic factors. Indeed, most recent studies on adaptation put forward the idea that the most important factors playing a role in resilience (the capacity of a society to adapt to change) are not natural but rather, those that play a role in a society's capacity at preparing for climate-induced changes.[1]

In the case of adaptation, policy building needs to take a new form because of adaptation's very nature. First, because climate as risk is redefining the perception of risk as such, from punctual and extreme events to recurrent, permanent pressure. Secondly, this is why the approach to adaptation policy design must change: it requires self-adjusting policies to constant yet uncertain change uncovered by science, territorialized observations. This needs to be combined with analyses at different and changing probability and uncertainty levels and thus varying (and uncertain) levels of success. These all meet at the intersection between vulnerability and more importantly, capacities. But how is this perceived and practiced at the local level by local administrations?

[1]At last, the international scientific community has recognized the importance of social issues: the fifth IPCC Assessment Report will specifically focus on the social dimensions of climate change for both mitigation and adaptation. Hence, the idea now largely recognized that climate change is only secondarily a hard science issue: it is far more a social science one.

Adaptation in French TCEPs

Adaptation became, in 2012, an obligatory sector of the new French TCEPs, but its application and the diffusion of this issue through different administrative levels differs from mitigation in several ways. First, adaptation has yet to enter most actors' awareness, aside from specialists. Its necessity is not perceived in large part because CC's impacts are not being felt nor experienced by actors living in developed countries. Second, adaptation is much less well scientifically understood. Indeed, projection and computer simulations of present and future impacts rarely go below a 100 km^2 area. Thus, the level of scientific and political uncertainty is much greater than with mitigation policies and makes both decision making and policy design more difficult. Third, adaptation is a far more complex issue than mitigation: understanding the natural impacts is only the first part of the process. Indeed, these impacts are not limited to the "objective," natural, biological, and morphological levels – whose frontiers do not often coincide with political-territorial boundaries but also require an understanding of the natural impacts' effects on human activities at the territorial level. Thus, natural sciences link to specific interests, administrative services, and economic activities come into contact with human activity and the social sciences. A third phase is thus required: evaluating a society's capacity at organizing itself to impacts, i.e., its resilience. Only then can we have a relatively good idea of a territory's vulnerability in the full sense of the word and only then can potentially cogent adaptation strategies be developed.

For political scientists, policy design extends to both the mechanisms through which policy goals are given effect, and to the goals themselves, since goal articulation involves considerations of *feasibility* (what is practical or possible to achieve in given circumstances given the means at hand). Adaptation thus represents a real challenge, far greater than mitigation in part because designing adaptation policies requires steps that include a high level of uncertainty and unknowns and thus lower potential of feasibility. How is one to about then? The following steps proposed here are "ideal" and rarely to be found in actual policy settings and framing, but they seem to be the goal to be attained:

(i) Identify what the *probable* increase in temperature might be at a *chosen* time frame (2030, 2050).
(ii) Identify the probability level of natural impacts (rainfall, heat, cold, avalanche, landslides, as well as impacts on living beings – plants and animals – such as reproduction cycles, migration, feeding areas, and growth rate).
(iii) Identify the impacts of these changes on human activities and population.
(iv) This is where resilience, both collective and individual, plays a key role: a younger population (aside from newborns) suffers less from a heat wave than an aging one; a ski-dependent local economy will be more vulnerable to a decline in snowfall, a semiarid-based agriculture will have to face even more arid conditions, etc. Generally, poorer, less educated populations are more vulnerable to climate change than wealthier, more educated ones.

Designing an adaptation strategy thus requires not only a relatively high level of natural scientific input but also an association with social sciences and economic territorialized analyses of what these impacts may mean in the future. But it also requires a different view of what the foundation for policy design and decision are: a backward management approach is necessary with, for example, a prediction for what these impacts might be in 2050 and then backtracking to what should be done in the short term in order to reduce the social and economic effects of future climate change. Adaptation is not a reaction; it is preparation to a specific, given, constraint based on as yet uncertain impacts in the future. The problem is that this constraint remains often uncertain. In order to reduce the high level of uncertainty of these impacts, a significant input of scientific expertise is often asked in the development of climate adaptation policy. But this expertise meets policy and institutional logics that may or may not favor its development (Young 2002a, b).

As an example, hydroelectric dams will be directly affected by variations in water quantity (either not enough or too much) as well as regularity. Indeed, in France, dams are in many regions used as equalizers of peaks in electricity demand, but they may start to fail filling this role if water is insufficient. As for water temperature, which has increased by a couple of degrees on average in most European countries in the last decade, it cannot go beyond 28° to cool nuclear power plants. Over this limit, a plant has to be shut down. In 2011, an energy crisis in France was very closely averted, when after over 2 months of high temperature and little rainfall, it finally started raining, avoiding the shutdown of a nuclear power plant. This raises the following very hard question: how is one to design a policy or a set of policies that can take these types of effects into account? Is a new approach to policy design necessary? The next section develops this section through two case studies: Dijon and the Gresivaudan. We will see that while the Gresivaudan offers a real example of our argument that adaptation necessitates a different model of designing policy, the Dijon case is more classical. This points to the importance of political decision framed by institutional constraints and experience. We then draw conclusions on the weaknesses and strengths of each.

Adaptation in the City of Dijon: Integration in Urban Planning

Dijon is a large city, with an extensive, mineralized historical center. Already vulnerable to urban heat island effects, the population suffered during the 2003 heat waves. Recent local studies show an important disparity in terms of heat vulnerability between the center (with little vegetation and parks) and the periphery. The city of Dijon launched its Climate Plan 2 years before the 2012 deadline. Dijon had been, several years before, well known for its environmental approaches in an urban setting but had lost this image in the last few years, surpassed by a few cities ambitious on climate and energy objectives. Dijon wanted to "catch up" and go beyond by implementing an ambitious climate plan, to coincide with a new tram network. Indeed, there is a strong multiparty political program called "Dijon ville écologiste" (Dijon, an ecological city) that aims at giving an ecological direction to all urban policies.

At the institutional level, the city's urbanism service is quite active and important in the political and budgetary landscape of the city's administration. It is also highly sensitive to ecological questions and, more specifically, to climate change issues. The work aimed at developing an adaptation strategy was headed by the urban ecology service, in coordination with the urbanism department. This department is closely linked to the city's urban developer agency which developed an ecodistrict standard (with several criteria taken into account such as water, energy, vegetation, energy standards, etc.). Urban projects had to follow these standards in order to be accepted by the city urban planning council. But the adaptation issue was largely unknown. More at issue, while there were individuals who knew about CC's potential impacts and adaptation, measures to address these impacts were not integrated in the services as practices or norms. To be noted: while the urbanism department was very present in the adaptation strategy development process, the elected official in charge of urbanism was not in charge of the TCEP. They did not share the same vision of urbanism nor of climate adaptation nor of its urban aspects. Indeed, economic arguments were more important to the first: What would be the impacts of costs of integrating adaptation measures in urban projects? What would be the benefits and for whom and when? Nevertheless, they agreed on the importance of developing an ecological urbanism.

Indeed, the city implemented an ambitious ecodistrict development policy, strong on energy efficiency – and mitigation – but weaker on other climate issues. Our task was to develop an adaptation framework and criteria for these new projects. Indeed, while planning and integration of mitigation measures in urban projects was well under way, adaptation appeared far more difficult, less well-known issue, filled with uncertainties in terms of likelihood of occurrence and impacts as well as time frame. In addition, an earlier multisectorial strategy had been proposed but had failed for several reasons, among which, it was judged to be too general, nonoperational, and not tied enough to its territorial setting and issues. While territorial data did exist on urban climate change vulnerability, those had not been translated into an operational approach. Thus, the decision was, first, to address urban adaptation issues. But the question was: Which ones?

The weakness of the previous approach, coupled with the political project (Dijon, an ecological city), and the desire to develop an operational adaptation strategy led to the adoption of a new approach: less ambitious, but more cautious and more gradual, and more sectorial, over a 3-year period, with two or three specific adaptation issues per year to be co-defined with elected officials and appropriate administrative services. In order to select the issues to be worked on, we first organized a series of multi-stakeholders' meetings (with semi-directive interviews, either individually or in small groups) in order to:

1. Understand administrative actors' level of knowledge of the adaptation issue in general.
2. Understand the level of knowledge of the adaptation issue on Dijon's territory specifically. This also allowed us to:

3. Identify key actors and resources that could produce or offer already produced knowledge and data. To be noted: the information produced was not always recognized by those who produced it as useful for adaptation, yet it was. Key actors were University of Bourgogne, Alterre Bourgogne – an ecological association – Météo France, the Regional authorities, and two national government regionalized bodies.
4. Identify potential issues to be developed in the first phase of the adaptation strategy.
5. Develop operational adaptation indicators and measures in urban projects.

But again, this raises the question: Which ones specifically? We then met again with these different actors in order to select the issues to be dealt with in priority. Several selection criteria were applied: political (the public image an issue would get, including the Dijon's ecological vision); a previous vulnerability study confirmed the risk of urban floods due to water overflow and very insufficient infrastructure; and the emergence of a new issue in the different discussions, and proposed by the project team – urban heat effects and measures to counteract it, including district and building conception approaches and vegetalization. This concurred with a previous study on CC's potential impacts on average rainfall and average urban temperature (associated with an aging population, also important to the actors involved). But even once identified, these issues can only remain nonoperational if a temperature increase scenario is not chosen.

Indeed, an increase of +2° would have only small effects, but climate studies' impacts on vegetation and rainfall and temperature show that an increase of +3° would, *probably*, have a *significant* impact. This raised a real debate among some of the actors: Why a +3° scenario rather than a +2°? National mitigation targets were defined (in 2010) according to a +2° scenario. And national climate change mitigation information campaigns were entirely based on a +2° scenario. The discussion mainly revolved around scientific arguments being thrown against institutional ones. Finally, the +3° scenario was *politically* chosen, the elected official in charge of the TCEPs using his decision power to resolve the issue, as he felt that the scientific arguments but also the precautionary (if one is ready for a +3°, then one is also ready for a +2°, but the opposite does not hold) one were valid.

The scenario chosen led to a few specific adaptation issues emerging, deemed to be both more important in terms of impacts and more likely to occur. Two of these could be associated closely under the same general theme – and associated to the importance of the urban setting: the fight against urban heat effects. Indeed, IPCC +3° projections show that before 2050, 2 years out of 3 would have the same mean temperature as the European 2003 heat waves (which killed 50,000 people), with the additional issue of an even older population by 2050. Two different approaches were co-defined in part because our benchmark of international studies showed that two main sources of the urban heat effect were bad spatial planning and lack of vegetation. In addition to this, another factor was interesting to the responsible elected officials: it would improve citizens' urban daily quality of life. In other words, improving spatial planning and increasing vegetation cover in an urban setting were no regret measures and were relatively certain to produce the effects expected.

A second benchmark of good urban adaptation and vegetalization practices in cities was undertaken. Results and evaluation of these measures for the Dijon contact were produced and diffused in different services and applied to a new urban construction project. A method by which these issues could be integrated in urban planning documents, in services' practices, and in the first phases of urban projects was also developed. Special attention was paid to the different phases of urban projects: measures to be integrated in the conception phase, those that could be integrated during construction, and finally, those that could be added to an already built project. For example, building orientation (north-south) and height need to be included in the conception phase (Is the aim to increase or to decrease exposure to the sun? Where can one integrate a pond for runoff water, which can also be used to increase cooling in the summer?), while planting specific species of trees (high and narrow or short but wide, and where? Is vegetalization on walls or rooftops possible?) can be done in the construction phase. Another issue emerged, strongly in this context: national historical building protection legislation narrows very much the scope of measures possible in the historical center and may even, in some cases, forbid vegetalization. This issue was still not entirely resolved at time of writing. While interesting, the final result falls outside the scope of this paper. More to the point, there are the lessons to be learned from the Dijon case for reflections on policy designs, and we develop those in the last section. It is now interesting to turn, as a counterpoint to the strategy developed in Dion, to the Gresivaudan case.

The Gresivaudan Case

The Gresivaudan is a semi-urban, complex geographic territory, with three main economic activities partly linked to its geographical diversity: the territory is made of a wide valley encased in high mountains. The third economic activity, in terms of economic revenue generated, is high mountain winter tourism – skiing and thus, highly dependent on snow fall. Low-altitude ski stations are already negatively affected by CC, with reactive "adaptive" actions such as artificial snow and attempts at diversifying activities toward summer tourism only being slowly put into place. The second economic activity lies in the valley, with the production of high-yield, very high-quality, low inputs, high revenue generating corn production for oil dedicated to high-tech processes. The first activity is nanomicrotechnologies, with the world's third most important research site, also in the valley.

CC impacts on these different sectors (as well as others, such as forest exploitation and pastoralism) and urban areas were thus highly complex and potentially key to wealth generation, employment, choice of housing, quality of life, and modes of living. It thus raised very sensitive issues for the majority of the population as well as for elected officials and heads of services. The adaptation strategy proposed was both experimental and ambitious: an integrated, holistic, multi-actors multi-issue adaptation comprehensive strategy. The method with which this strategy was designed was thus deeply different from the one used in Dijon. So were the results. Our choice of approach in assisting the territorial administration in designing its adaptation strategy was due to several factors, both natural and human.

The natural set of factors was the geomorphological diversity, with a valley between two mountain chains with different rock formation, one retaining water more than the other, with different vegetal species associated. These three geographical zones were linked to each other by a fourth, the mountain slopes flanking the valley on both sides, with different levels of access and economic activity, and peopled with sparse small villages, on the way to ski stations. The adaptation strategy development team and the administration were very keen on understanding the impacts of CC on these different natural (and human) zones, associated to different economic activities (especially winter sports on one mountain chain), corn production, and nanomicrotechnologies. Note as well that the valley is far more urbanized than the other zones and at risk of flood, due to a river running through it. Note that in this phase of the process, we use notions and terms that are very close to social geography.

The second set of factors was institutional. The Gresivaudan administration had decided to be ambitious and experimental in their adaptation approach but also insisted on being operational. They also possess a rather strong territorial identity that they wish to put forward. Thus, they felt that operational recommendations on our part had to be based on a clear understanding of their territory's specific issues and form. Territorial-based data needs to be accumulated, to which the team could only concur since adaptation is first and foremost a local issue that needs to be developed from that level. But the Gresivaudan administration was also more ambitious on another level: the development of a holistic adaptation strategy was to be the first step in the development of a permanent program that had to include the development of territorial multi-issue multi-stakeholder knowledge for CC adaptation, made possible by the permanent integration of scientists and studies in the adaptation process. Thus, knowledge development was seen as an essential part of a successful adaptation strategy. This is important: usually, public policy is seen as a closed process, where the implementation of a policy is seen as the last phase. Sometimes, an evaluation is undertaken but this is more the exception than the rule. Not in the Gresivaudan's case: evaluation and reformulation of issues, their importance, and impact evaluation are seen to be as a continuous process, to be adjusted according to new knowledge, real and predicted temperature increases. Thus, the administration saw its adaptation strategy not only as an end (be adapted to future climate change impacts) but also as a means, an experimental laboratory by which understanding of all phases of adaptation would be improved.

This was greatly helped by the fact that the elected official in charge of the emerging TCEP was a climatologist working for a national agency (Météo France). As a scientist, he was thus very well informed and up to date on climate issues (as well as aware of the uncertainties linked to adaptation). And, as an elected official, he was also "politically savvy" and sensitive to both internal political dynamics and to the population. He was also very insistent that the recommendations be understandable, operational, and *potentially* (he was also aware that one could not ask hard results from an adaptation strategy) effective for his territory. But faced with such a complexity, how were we to proceed? This is where a third set of factors needs to be taken into account: the role of science. Indeed, one may wish to develop scientific knowledge but there has to be the means to do this.

The Gresivaudan territory is located near Grenoble, a midsize university city, with a highly active scientific, and very diverse in terms of disciplines, community working on climate change. This represented a real opportunity: use this scientific community to gather information and data on the potential impacts of a +3° scenario on the territory. Rather than overlooking the uncertainty issue, and pretend to offer hard answers, we opted for the following approach: identify with these scientists through collective work what the impacts of a +3° scenario would be on that territory according to a 4-level scale: high, mid, low, and unknown probability. This was then coupled with a 4-scale potential severity of CC impacts on, first, the "natural" world.

Our diagnostic of the territorial vulnerability, through multipartenarial working sessions, included the following sectors, with a map that offered a visualization of the areas and their vulnerability:

- Water resources: impacts on water quality and availability
- Natural risk: floods, storm flashfloods, etc.
- Biodiversity
- Agricultural and forest activities
- Mountain tourism: especially snow levels for ski stations and CC's economic impacts
- Energy and economic activity energy production for dams and impacts on tertiary activities and industrial zones (including water management and runoff)
- Urban planning and buildings, including impact on behaviors and uses (i.e., air-conditioning in the summer and its impacts on energy demands)

Local nonscientific and nonadministrative actors were also involved, such as forest managers, owners and exploiters, industrialists, farmers, etc.

The second phase of working sessions aimed at building an integrated adaptation strategy, composed of different policy sectors. It included both scientific actors and institutional actors (forestry, agriculture, industries, urbanism, mobility, and others) working together on the probable effects these impacts could have on activities. The goal was to move from natural vulnerability to socioeconomic vulnerability of natural impacts, with two other, policy-oriented, goals in mind. First, we were able to define levels of priorities to the different issues in the short, middle, and long term. Then, discussions and policy-setting, policy-building, and actions were co-constructed between the adaptation team and the different heads of the territorial administration. This was also used to improve knowledge of administrative actors, so that they would start integrating the adaptation issue in their specific areas of competence and actions.

Conclusion: Lessons from Both Case Studies

Different lessons can be learned from these two case studies, in terms of internal and external factors in how adaptation policies were constructed. Note that while population density or urbanization levels played a role on specific actions and policies that are to be built, this did not play a role in *how* the strategies were built, and only a minor role on the issues chosen: organizational framework and local scientific resources were clearly more important.

In both cases, probable and high-impact territorial natural vulnerabilities were first identified, and then, "social" vulnerabilities were declined. In both cases, a collective (institutional) decision was made regarding which issue was to receive priority, based on the previous more scientific and technical assessments. In Dijon's urban setting, the urban heat island phenomenon and vegetalization were chosen, whereas in the Gresivaudan, an identification of all possible impacts was made, and then priorities defined. The urban heat effect was not a priority, in large part due to the fact that it is a semi-urban setting. But more significant differences, in terms of policy design, can be identified.

In Dijon, the adaptation strategy is being built piece by piece, two issues per year over several years, whereas in the Gresivaudan, the aim was to build in about 1 year an integrated, multisectorial adaptation strategy from the very first phase of the TCEP's construction. The aim to create a permanent scientific knowledge development was also decided from the onset. The differences between the two cases were due to several reasons. In Dijon, a previous "failure" in building the adaptation strategy had led to an attitude of precaution on the part of the administration, who wanted to avoid another failure, so close to the legislative 2012 December 31st deadline. But also, and perhaps more importantly, this failure ran against the city's political vision "Dijon, an ecological city." Dijon's step-by-step strategy offers clear advantages: each step is more likely to succeed in terms of integration by services and operational measures, since it requires less change at once and less human power. It also is less disrupting of everyday work habits, skills, and networks. It is also much easier to correct if need be.

Another factor was internal, in the administration itself, which offers a few reflections on Young's work regarding internal institutional obstacles (2002a, b). The different visions between Dijon's elected official in charge of the climate plan and the official in charge of urbanism meant that issues interesting to both had to be defined. The debates did not prevent the development of a strategy, on which both essentially agreed. In the Gresivaudan, the elected official was a climatologist who not only understood the scientific aspects of climate change but also the potential risks and social and economic and political impacts. He had an integrated and holistic conception and expected, explicitly and from the start, a corresponding adaptation strategy, which had to be *operational*, on which both cases agreed.

Another difference was the territorial scientific resource. As pointed out earlier, the Gresivaudan Valley is located near a Grenoble where, by a series of historical coincidence and scientific laboratories' strategies, research on climate change and its impacts has been developed for several years and in many disciplines, and this is important, *including in the social sciences*: technologies, urbanism, sociology, political science, natural and social geography, economics, etc. This is coupled with a high level of interest, knowledge, and policy development in the field of energy and climate change on the part of the territorial administration. Hence, it was relatively easy for the team to gather different resources to help identify the natural and social impacts, their probability of occurrence as well of probable level of severity. The social and institutional resilience aspects were explored through a social science and economics perspective.

Both methods for building an adaptation strategy have pros and cons. The Dijon strategy requires less effort during the initial phases and may well be easier to internalize and apply by services, as well as conditions in urban projects imposed on constructors or architects. Initial successes in specific sectors then help diffuse the approach to other services, even though this may take more time. In the second phase, the project is to take the previous year's work and integrate the recommendations in daily work routines and institutional texts, in the urban development services, by integrating new adaptation (urban heat effects and vegetalization, as well as the use of water) norms and methods in urban projects. The risk is that the strategy could remain sectorial and not be integrated transversally in the different structures and services. It could eventually lose in efficiency and, or even, face contradictions and tensions between services that could slow down or even block adaptation strategy's diffusion to other departments.

As for the Gresivaudan, it is too early yet to say whether its integrated holistic strategy will not be too complex and heavy to handle for a rather small administration. But if the transversal work is done, it fares a better chance at being efficient and cost effective in more areas at the same time. Its drawback is its potential (un) replicability to other territories. Indeed, not all elected officials (who give the political leadership and general direction and level of ambition of the TCEP) in charge are climatologists and thus understand as well the climate change issue and its link to impacts and social vulnerability. Nor do most territories have such a wealth of scientific expertise on adaptation at its disposal. Taken together, the opportunities for scientific input to the territorial agenda setting, policy objectives, and design were quite specific to the Gresivaudan. Perhaps, too specific for replicability?

Our adaptation strategy development approach was indeed developed so as to be replicable: evaluation of potential impacts on the natural milieu, then on the social one, and finally, evaluation of the territorial vulnerability and resilience. Efforts at improving resilience are an integral part of the Gresivaudan's strategy at developing scientific knowledge on a permanent basis.

A last point needs to be addressed here. Organizational framework and local scientific resources were identified as being clearly significant factors in the elaboration of the adaptation strategies. But one can wonder whether the natural factors did not also play a role, even if indirect. Dijon is a "typical" city with typical functions and services associated to urbanization. It is located in a homogeneous geomorphological (flat, with a few rivers) and climate milieu. But the Gresivaudan territory is made up of two different mountain chains and a valley, with different significant economic activities associated to each, to which we can add high-tech research and development, with different milieus, interconnected by population movements and activities, with related social and economic issues. It may be that these natural characteristics are more conducive to a multisectorial and holistic approach, i.e., a more complex socioeconomic system requires a more complex and holistic adaptation strategy. Further research, comparative as well, is necessary on this point. This also raises a more anthropological and ecopolitical theory question: How much does natural territory affects policy, its design, and its implementation?

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Disaster Vulnerability in the Policy Context of Bangladesh: A Critical Review

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Abstract

This chapter attempts to have an in-depth understanding of the climate change policy context of Bangladesh with regard to the notion of disaster vulnerability as a policy concern. The chapter reviews the policy from a social vulnerability perspective. With regard to the socioeconomic and environmental context of Bangladesh, it develops an analytical framework to examine the climate change policy. There is a lack of conceptualizing disaster vulnerability in policy formulation that makes it biased towards "physical adaptation" measures to reduce disaster risk. The political economy of climate change initiatives in Bangladesh leaves little scope to address vulnerability of grassroots communities. The chapter argues that in a country like Bangladesh where lack-of-development-led problems are persistent, there is an urgent need to develop context-responsive policies and action plans that should address the causes and dynamic processes of disaster vulnerability and lack-of-development issues in an integrated manner. Existing climate change policies do not address the structural dynamics of disaster vulnerability adequately. To this end, the chapter suggests policy-relevant insights towards the formulation of people-centered policies and strategies for Bangladesh.

Keywords

Climate change • Disaster • Vulnerability • Political economy • Policy

Introduction

Bangladesh is recognized worldwide as one of the countries most vulnerable to the impacts of climate change (WB 2012). This is due to its unique geographic location, dominance of floodplains, low elevation from the sea, high population density, high levels of poverty, and overwhelming dependence on nature (CCC 2007). Global warming has affected weather patterns and disrupted variability and trends in climate. This is resulting in an increase in climate-related extreme events like heavy rainfall, flood, cyclone, storm surge, etc. (Alam 2004; Alam and Murry 2005; Mahtab 1989). These extreme events claim thousands of lives, destroy assets and properties, and disrupt livelihoods of hundreds of millions of people. Because of sea level rise, coastal Bangladesh has already been experiencing the worst impacts especially in terms of coastal inundation and erosion, saline intrusion, deforestation, and loss of biodiversity (BCAS et al. 1996; BCAS and BUP 1994; BIDS 1994). More than 40 million people of Bangladesh still live in poverty. Many of these people live in remote or ecologically fragile parts of the country, such as river islands (*chars*) and cyclone-prone coastal belts, which are especially vulnerable to natural disasters. In the recently released Poverty Reduction Strategy Paper (2009–2011) and the Sixth Five-Year Plan (2011–2015) (GOB 2012), the government has reaffirmed its commitment to the Millennium Development Goals (MDGs) targets, including halving poverty and hunger by the year 2015, through a strategy of pro-poor growth and climate-resilient development.

Climate change will severely challenge the country's ability to achieve the high rates of economic growth needed to sustain these reductions in poverty. The government has recognized climate change as an important issue and attempts are being made to incorporate potential response measures for reducing impacts of climate change into overall development planning process. Many sectoral policies have recognized the issues of climate change and highlighted the importance of integration of environment and resource management for achieving sustainable development of the nation (Parvin and Johnson 2012; MOEF 1995; GOB 2003). However, until 2005 the government of Bangladesh did not have any climate change policy to address anticipated impacts of climate change. The National Adaptation Program of Action 2005 (NAPA) (MOEF 2005) is the first policy document in this line. In 2009, Bangladesh government has prepared the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) (MOEF 2009). Both policy documents have recognized disaster threats and emphasized on the institutional and functional arrangements required to prepare responses to and recover from disaster events. However, the policies conceived disaster risk and vulnerability from a hazard-centric technocratic approach where the physical impacts of climate change are considered as indicators of disaster vulnerability with little or no consideration of the underlying structural systems, i.e., the social, economic, and political systems that make people vulnerable to natural hazards. The policy context is yet to conceptualize the notion of disaster vulnerability with regard to the structural factors and dynamic processes shaping it. This policy lag is reflected explicitly in the domination of physical intervention-biased adaptation and mitigation strategies outlined in the said documents.

Conceptualizing Disaster Vulnerability as a Policy Concern

An increasing number of devastating disaster events all over the world has caused disaster researchers to rethink the nature and causes of disaster vulnerability. Instead of regarding disaster as a purely physical occurrence, requiring largely technological solutions, as was widespread until the 1970s, scholars have attempted to unmask the naturalness of disasters since 1980s. The dominance of technical interventions focused on predicting hazards or modifying their impacts have been increasingly challenged by alternative approaches that examine disasters through the lens of vulnerability, primarily viewed as the result of human actions. This advancement in disaster studies can be understood in terms of two competing paradigms – the technocratic or hazard-centered paradigm and the constructivist or structural paradigm (Hilhorst 2004; Smith et al. 1999; Oliver-Smith 1996). The technocratic paradigm is dominated by behavioral approach, focused on geophysical processes to monitor and predict hazards, where social scientist is brought in to explain people's behavior to risk and disaster and to develop early warning mechanisms and disaster preparedness schemes (Oliver-Smith 1996). This hazard-centered approach was challenged by the researchers from social sciences and applied sciences arguing that disasters are not primarily the outcome of geographical processes but rather should be understood as the interaction between hazard and vulnerability (Hewitt 1983).

In the structural paradigm social vulnerability is the key to the understanding of disaster risk based on the premise that while hazards are natural, disasters are not (Cannon 1994). Structural forces, such as social, economic, and political processes, generate unequal exposure to risk making some people more vulnerable to disaster than others, and these inequalities are largely a function of the power relations operative in every society (Cannon 1994; Hilhorst and Bankoff 2004; Wisner et al. 2003). Thus, vulnerability is socially constructed and is the result of structural processes (Susman et al. 1983; Lewis 1999). For a particular community, vulnerability to disaster is shaped by the multidimensionality of disaster impacts by combining both the structural and environmental dimensions of disasters (Blaikie et al. 1994). Therefore, during climate change policy formulation, it needs to be understood in the context of social, political, and economic systems that operate on national and even international scales: it is these which decide how groups of people vary in relation to health, income, building safety, location of work and home, and so on (Wisner et al. 2003).

In the structural paradigm of disaster research, the root causes of disaster vulnerability are expressed in terms of various social, economic, political, and physical aspects. Blaikie et al. (1994) expressed the underlying factors shaping vulnerability in terms of ideological root causes, dynamic processes, and unsafe conditions into causal chains. In the "pressure and release model," the notion of vulnerability is explained in terms of social pressures and relations from a global to local level. At the global level different forms of relationship between society and nature, i.e., the social, political, and economic structures, are identified as the ideological root causes of disaster vulnerability. At an intermediate level, the dynamic processes include population growth, urban development and population pressure, environmental conditions, loss of ethics, etc., while at a local level the unsafe conditions include social fragility, potential harm to natural and built environments, poverty, etc. In this approach, disaster prevention and mitigation is conceived of as releasing the pressure of what is global over what is local and signifies intervention at each level (Wisner et al. 2003; Wisner 1993; Cannon 1994; Blaikie et al. 1994). Unsafe condition at local level is shaped by the baseline status (i.e., the basic needs such as income, food, health, education, and shelter) and degree of exposure of individuals to hazards. Irrespective of hazard circumstances, degree of individual's accessibility and reliance on resources determine the first layer of vulnerability, i.e., the baseline vulnerability. Disaster risk is generated as a result of the difficulties that some social groups or households have in accessing resources and facilities which are important to build capacity to face potential disaster (Sen 1981; Chambers 1989; Winchester 1992). Thus, baseline vulnerabilities change over time through changes in one's institutional and economic position, condition of shelter, food, and health, and these changes are affected by environmental changes (Adger and Kelly 1999).

Increased attention to environmental processes and human-induced climate change has marked the emergence of another paradigm – complexity paradigm in the 1990s that takes the constructivist paradigms of disaster a step further (Hilhorst 2004). This paradigm was based on systems theory related to the theories of complexity, chaos, cybernetics, and complex adaptive systems. In system approach, disaster vulnerability is shaped by the complex interaction among three major systems – (1) environmental systems, which include the physical dimensions of earth's hazardous events; (2) social systems, which include the structural and demographic characteristics of the communities that experience disasters; and (3) constructed systems, which include the components of man-made built environment (Mileti 1999). This approach offers a venue for understanding vulnerability and disaster in terms of multiple realities. Instead of capturing and controlling complexity, the challenge then becomes to acknowledge multiple realities shaped by culturally and politically informed selections and to embody the realization of complexity in developing institutional relations, mediations, and identities (Shackley et al. 1996). Regarding response to risk and disaster, Hilhorst (2004) interprets the complexity theory in terms of three main social domains – the domain of "science and disaster management," the domain of "disaster governance," and the domain of "local responses." They are the respective domains of scientists and managers, bureaucrats and politicians, and local producers and vulnerable people. Disaster responses come about through the interaction of science, governance, and local practices, and they are defined and defended in relation to one another (Hilhorst 2004).

The Analytical Framework for Policy Review

Despite the noteworthy advances in conceptualizing disasters, there is yet to develop a consistent and coherent theory of disaster vulnerability. This is mainly due to the inherent complexity and multiple realities of disaster impact and vulnerability. However, real-life disaster response requires a consistent and coherent conceptual framework to help formulate policies responsive to a given social, political, and environmental context. With an aim to understand the climate change policy context of Bangladesh, disaster vulnerability in this chapter is conceived as the societal condition of grassroots community created by the particular social systems and power relations in which the state apportions risk unevenly among its people and in which society places differing demands on the physical and natural environment. As suggested by Blaikie, Wisner, and Cannon (Wisner et al. 2003; Wisner 1993; Cannon 1994; Blaikie et al. 1994), this societal condition stretches along the three-tier vulnerability continuum from local to global level, where the condition is shaped by the dynamic interaction of ideological root causes at global level, dynamic processes at intermediate level, and unsafe condition at local level. Ensuring "safe conditions" at household level is fundamental to reduce local baseline vulnerability and enable the household to move onto the intermediate level of vulnerability continuum. The dynamic processes at intermediate level involve development needs such as basic infrastructure and services, population pressure, livelihood opportunity, natural resource base, environmental conditions, social capital, and so on. These processes are attributed to the structural forces interacting at global level – such as social deprivation, economic disparity, unequal distribution of wealth, global warming, power relations, and so on. Climate change policy should address these interacting dynamics as a strategic focus for adaptation through disaster risk reduction.

Underpinned by this notion of disaster vulnerability, this chapter attempts to examine the climate change policy context of Bangladesh in light of the analytical framework shown in Fig. 1. The framework comprises two major components to analyze climate change policy in Bangladesh. First is the climate change context; it examines the conceptual focus and contextual brief of the policy document.

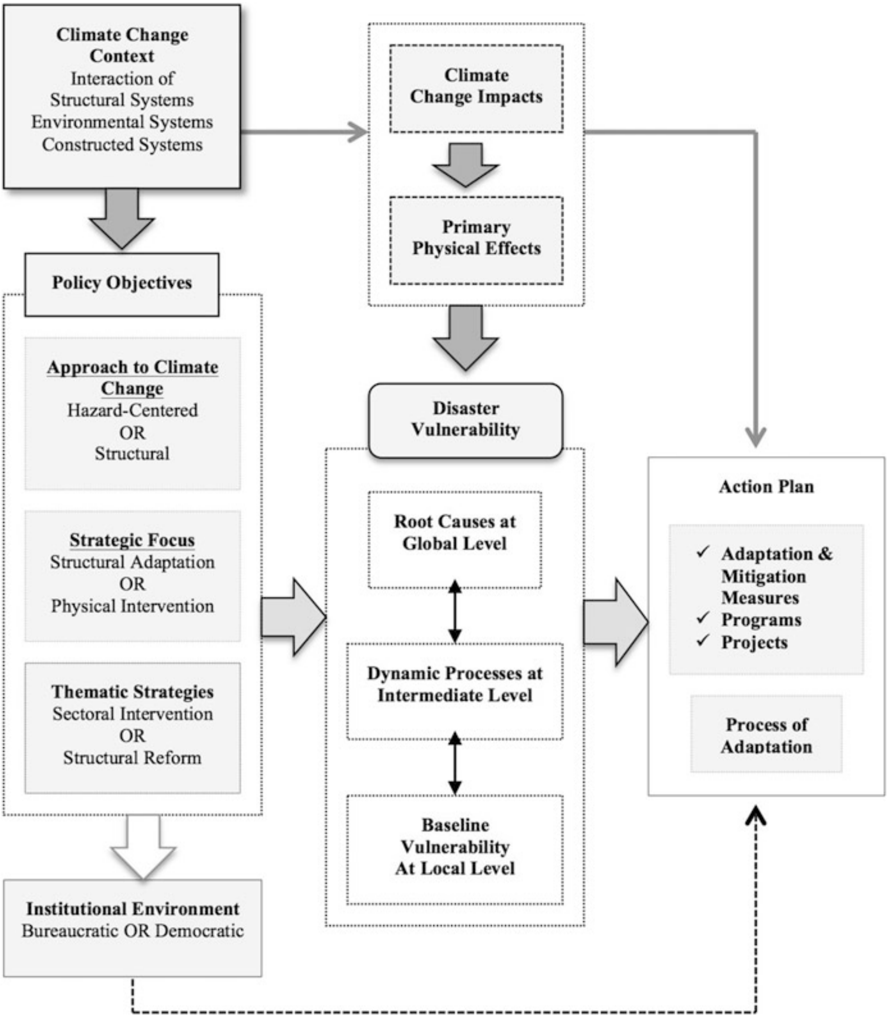

Fig. 1 Analytical framework to examine climate change policy

This includes evaluation of policy objectives, strategic focus, and institutional environment with regard to climate change impacts and vulnerability. Second is the action plan; it examines the thematic areas of action plan, adaptation and mitigation measures, and detailed programs and actions with regard to the strategic focus and objectives.

The Political Economy of Disaster Vulnerability and Climate Change

Since Bangladesh has got its sovereign identity in 1971, the rest of the world has known it mostly as a disaster-prone country with high level of poverty. Despite having very rich sociocultural background, natural resources, and geopolitical opportunities, this image and identity of being a "disaster-prone" and "poor" country have always been singled out and portrayed with much enthusiasm into the international arena by most of the policymakers and power elites of this country. Promulgating this image has been associated with a hazard-centered attitude to disaster vulnerability. This attitude has made profound impacts on the national policy initiatives and actions concerning the climate change issues. Over the last three decades, with the financial support from international donors and development partners, the government of Bangladesh has invested over $10 billion (at constant 2007 prices) to make the country "less vulnerable" to natural disasters. These investments in many cases included large-scale physical adaptation measures such as flood management schemes, coastal polders and embankments, cyclone and flood shelters, and the rising of roads and highways above flood levels (MOEF 2009). Owing to the disaster-prone image and hazard-centered attitude, the investment went mostly for physical intervention, while reducing the root causes of disaster vulnerability has largely been ignored.

Within the key policy documents of Bangladesh, climate change as a strategic focus was absent until 2005. Environment and sustainability, as the concerns for development, were first addressed in the Fourth Five-Year Plan (1990–1995) and received more emphasis in the Fifth Five-Year Plan 1997–2002 (GOB 1998). Chapter 10 of this plan, "Environment and Sustainable Development," recognizes the need for integration of environmental issues into development planning and activities and suggests a policy outline and brief strategies for sustainable environment management. The plan mentions "disaster management" in subsection 10.8 of this chapter and suggested five measures, mostly physical, to reduce "disaster impact" – (1) massive afforestation, (2) construction of appropriate housing and cyclone shelters in the coastal belt and raised earthen platforms in the flood-prone areas, (3) construction of strong embankments in the coasts and islands, (4) implementation of an effective early warning system, and (5) incentives and awareness creation at the grassroots level. The underlying factors other than natural hazards that make a group of people more vulnerable to disaster impacts were completely overlooked in this plan.

Climate change, as a main policy focus, was first incorporated in the National Adaptation Program of Action (NAPA) (MOEF 2005) in 2005. The policy suggested future coping mechanisms to reduce adverse effects of climate change, including variability and extreme events, and to promote sustainable development. It outlined 15 adaptation strategies that included several measures for sectoral intervention. It also outlined some facilitating measures such as capacity building, research, and dissemination of knowledge and information. The policy emphasized physical vulnerability to climate change and accordingly it suggested large-scale physical intervention projects. The conception of social vulnerability is literally absent throughout the document. NAPA had never been implemented; however, building on this document, the then government had prepared and adapted the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) in 2008. BCCSAP was prepared as a response to the decision of the Seventh Session of the Conference of the Parties (COP7) of the United Nations Framework Convention on Climate Change (UNFCCC). The post-NAPA preparation of BCCSAP was one of rapid development in policy context targeting the then Copenhagen Summit. This quick revision of national policy suggests that earlier documents might have been prepared hastily to tap into the growing possibility of international funds in climate change adaptation (Nicola et al. 2011). It is also not unlikely that the possibility of harnessing international finance for adaptation might have been a reason to identifying costly physical interventions.

Building on the BCCSAP 2008, in 2009 the government of Bangladesh prepared the Climate Change Strategy and Action Plan 2009 (BCCSAP 2009) which is at present the most important climate change policy document in place. The BCCSAP 2009 mentions six key mitigation measures. Most of the adaptation and mitigation measures, however, are physical, immediate effects centered, short to medium term, and to be achieved through external intervention. The most recent policy document, Sixth Five-Year Plan (2011–2015) (GOB 2012), includes climate change issues as an integral part of development plan. Chapter 8 of this plan, "Environment, Climate Change, and Disaster Management for Sustained Development," suggests supporting communities and people in rural areas to strengthen their resilience and adaptive capacity as a high priority for the coming decades. However, the document outlined its target based on benchmarks identified against the six-pillar framework of BCCSAP 2009. As a whole, the policy context suggests a hazard-centered attitude to disaster vulnerability, which is reflected explicitly in the adaptation and mitigation strategies that focused more on "physical vulnerability" to hazard than on social vulnerability to disasters.

Alongside the image of a "disaster-prone" country coupled with the "hazard-centered" attitude to disaster vulnerability, a number of political economic factors make the pursuit of root causes of disaster vulnerability less attractive for the power elites and policymakers. Three main obstacles in this regard are characteristic to the institutional environment – (1) top-down development paradigm and technocratic bias to climate change, (2) hidden power struggles and lack of coordination in the institutional environment, and (3) lack of political will and vested interest of the stakeholders.

Top-Down Development Paradigm and Technocratic Bias to Climate Change

Historically the process of development has been dominated by bureaucrats and power elites, who are more concerned about the development work outlined in the national policy and programs at national level than the people-centered initiatives needed by people living in the disaster-prone areas like coastal belts, char island, and urban informal settlements (Taher 2003). The existing top-down development process and technocratic approach to climate change risk management leaves little scope for participation of the disaster-affected communities in the policymaking and implementation process. Even with the recognition of climate change adaptation and mitigation as integral parts of development process, the conventional attitude to development works undermines context-specific and community-based responses to climate change. The responses are therefore more about physical construction, pre-disaster warning system, and post-disaster relief and construction management, leaving little or no room for the active participation in terms of representation and ownership of the grassroots communities. Subsequently, the rigid policy institutional environment allows no mechanisms through which the vulnerable communities and households can influence national policy and development process.

Hidden Power Struggles and Lack of Coordination in the Institutional Environment

The institutional structure dealing with implementation and monitoring of climate change policies at the local level comprises three broad categories of organizations – public sector (e.g., administrative departments, elected local government bodies), private sector (e.g., NGOs, profit-oriented business concerns, donor agencies), and community-based social groups (e.g., *Shalish committee*, *Samiti*, school committee, branches of political parties, religious committee). The government sector has a three-tiered structure of elected local governance – *Zila Parishad*, *Upazila*, and *Union Parishad* (UP), at district, Thana or subdistrict, and village level, respectively. The public administration system generally follows a vertical pattern of authority where local bodies are linked vertically with its respective Ministry in Dhaka with a minimum delegation to the lower levels. Disaster management, adaptation, and mitigation initiatives are coordinated and monitored at district level and subdistrict level. The coordination mechanism at *Upazila* level is useful but only to a limited extent at the post-decision stage (Taher 2003). There is no room for the local level bodies to coordinate at the policymaking or planning stage.

Being without elected representative for a long time, only recently (in 2011) the senior district level leaders of the ruling political party have been appointed as the *Zila Parishad Proshashok* (District Administrator) with very limited power and authority. Among the three tiers of administration, *Upazila* is considered to be pivotal in the decision-making structure of the government having relatively better linkage and contacts with grassroots people through the *Union Parishads*. But in reality, the *Upazila* chairman, with no executive power, seems to exist with no natural upward link, and the UPs can barely relate to similar bodies of administration above. This situation has given rise to a very strange and inconsistent pattern of governance, which promotes a rather contorted system of hierarchy and lack of coordination (Taher 2003). Even though the *Upazila* chairmen are the responsible persons, in effect the Upazila Nirbahi Officer (UNO), if not the Member of Parliament (MP), exercises real power. In many instances, the MP's interference and influences of other political leaders in local level decision-making and resource allocations also contribute to the disparaging governing system (Siddiqui 2000). In the absence of a democratic structure, it is further aggravated by the rivalry of two groups of officers of the civil service cadres at district and subdistrict levels. The *Union Parishad* (UP) is currently the only local administrative tier closest to the grassroots communities. But despite having a legitimate mandate to "govern," the UP chairmen are unable to assert their authority because they have to almost fully rely on resources or block grants under the Annual Development Plan (ADP) sanctioned from the central government, which often comes late and is far too inadequate to address disaster vulnerability of the local communities (Verulam 2002). However, in some UP's where the chairman is in "good power relation," can wield more financial support and sanctions from above (not necessarily from the electorate), for his constituency. But sometimes success through this informal and rather partisan ways of dealings outside the institutionalized procedure often leads to financial corruption and jealousy and rivalry among the local administration (UZ), resulting in tacit noncooperation (Taher 2003).

Lack of Political Will and Vested Interest of the Stakeholders

Disaster-prone Bangladesh and sufferings of the affected communities bring financial gains, job opportunities, fame, and wealth for a large number of people from different strata of society from home and abroad. These people have their own interests gained through a wide variety of involvements in the process of climate change impact and adaptation. Processes of policymaking, program formulation, research, consultancy, preparation of action plan, international collaboration with donors and aid agencies, project implementation, and so on predominantly involve those who are not "disaster vulnerable." Therefore, for those with vested interest in climate change impacts, the question of whether the initiatives truly build resilient community by eliminating the underlying factors shaping disaster vulnerability or not is rather less important than continuing with whatever initiatives are there, at any cost. Given this national and international network of vested interest surrounding climate change issues, it is difficult to make any paradigm shift in the possessive and defensive mind-set of the concerned policymakers, power elites, and other stakeholders about what makes people vulnerable to natural hazards. Rather the existing hazard-centered mind-set gives them indemnity of the denial of their social responsibility to the grassroots people who are the victims of the unequal social system and power relations. Given this lack of political will, it is hard to challenge the structure of interests in favor of reducing vulnerability of the poor. The interests that must be influenced in order to reduce disaster vulnerability are the powerful elites and political parties with wealth and power over issues such as decentralization of power and bottom-up democratic governance. Only those with high levels of commitment – and power themselves – could consider such a risky venture.

The Bangladesh Climate Change Strategy and Action Plan 2009: A Critical Review

Bangladesh Climate Change Strategy and Action Plan 2009 (MOEF 2009) is the most recent and important climate change policy. It is in fact a revised version of the BCCSAP 2008 and has been prepared by the current government as a part of the overall development strategy of the country. Climate change constraints and opportunities are being integrated into the overall plan and programs involving all the sectors and processes for economic and social development. The policy is divided into two parts, comprised of six sections and an annex. In five sections part one includes the context, outlines the implications and likely impacts of climate change, and provides an overview of different adaptation strategies and mitigation measures. It outlines six pillars or broad areas of strategic intervention. Part two is comprised of section six and an annex provides the strategy with a 10-year action plan based on six pillars. A set of 44 programs under the action plan is outlined in the annex.

Conceptual Focus: Disaster Vulnerability in BCCSAP 2009

Understanding the notion of disaster vulnerability as a conceptual basis is crucial for climate change policy formulation. The strategy has a hazard-centered conceptual focus and deals with climate change issues from a centralized technocratic approach. Lack of conceptualization of the meaning and causation of disaster vulnerability is evident in different components of the policy statements. For example, in the introduction, it states – "Given the specific nature, however, of the problem of climate change particularly those related to future bio-physical and natural processes which are yet uncertain and the intimate link of the relevant national actions with international negotiations for emission control as well as their financing and technological support by and from the developed countries, for continuous monitoring of processes and events (natural, scientific, and negotiations) the Action Plan needs to be coordinated by a body such as a Climate Change Unit specifically created for the purpose by the ministry of Environment and Forests" (MOEF 2009, p. 3). The statement reveals that the policy conceives climate change primarily as a biophysical and natural problem, subject to technological solutions.

There is no definition of disaster vulnerability, neither any explanation of the underlying factors, causes, or dynamic processes that shape vulnerability throughout the document. It mentions the term vulnerability at several sections merely as a general word that refers to its literal meanings such as susceptibility, weakness, defenselessness, helplessness, exposure, etc. Table 1 shows specific examples of indiscriminate use of the term vulnerability throughout the document.

Table 1 Use of the term vulnerability in BCCSAP 2009

Sections and page no.	Use of the term vulnerability	Varied terminology
Message, p-xi	We are most *vulnerable* to climate change, and consequently adaptation is our priority	Vulnerable
Preface, p-xv	Poverty eradication and increased well-being of all *vulnerable groups* in the society with special emphasis on gender sensitivity	Vulnerable groups
Summery, p-xvii	Bangladesh is one of the most *climate vulnerable countries* in the world and will become even more so as a result of climate change	Climate vulnerable countries
Summery, p-xvii	Pillar one – food security, social protection, and health: food security, social protection, and health to ensure that the *poorest and the most vulnerable* in society, including women and children, are protected from climate change and that all programs focus on the needs of these groups for food security, safe housing, employment, and access to basic services, including health	The poorest and the most vulnerable in society, including women and children
Summery, p-xviii	Pillar six – capacity building and institutional strengthening: the needs of the *poor and vulnerable*, including women and children, will be prioritized in all activities implemented under the action plan	Poor and vulnerable
Context, p-2	The challenges now facing the country are to scale up its preparedness and resilience and protect the lives and livelihoods of the people, especially the poorest and the most *vulnerable families*, including women and children	Vulnerable families
Climate hazards in Bangladesh, p-8	Flood: during severe floods it is *the poorest and most vulnerable* suffer most because their houses are often in more exposed locations	The poorest and most vulnerable
Adapting to climate change, p-18	High incidence of poverty and heavy reliance of poor people on agriculture and natural resources increase their *vulnerability* to climate change	Vulnerability to climate change

Source: Extracted from MOEF (2009)

Climate Change Context in BCCSAP 2009

The background discussion on the core socioeconomic reality provided in the document sheds light on the need for accelerated development through poverty eradication. The strategy is underpinned by the conception that accelerated development is the most effective way to eradicate poverty and build resilience to climate change. It conceives the poverty issue from a traditional economic development perspective and considers poverty as a development problem of a particular socioeconomic group of people living in a particular area (disaster prone). Core issues, such as what makes some people poorer while others richer?, is poverty the result of development or lack of development?, what are the causes of poverty?, and are the poverty issues local or global?, are addressed inadequately in the background section of the strategy. Addressing these issues is important to understand how natural hazards turn into disasters for a particular group of people and what makes some people vulnerable to disaster, others not, within the given socioeconomic and political systems.

Thus, the document lacks focus on the structural dynamics and political economy of poverty and development in the context of Bangladesh. The strategy outlines the climatic context in terms of “climate hazards in Bangladesh” and “impacts of climate change.” It summarizes the context as “Likely impacts of global warming on Bangladesh and required investment” in Box 8 (MOEF 2009, p. 26). The policy highlights climate change issues in terms of “global warming,” “immediate impact,” “result,” and “investment needed” (MOEF 2009, p. 26). It suggests adaptation and mitigation measures in terms of “investment needed” and refers to the goal in terms of “social protection for the vulnerable/community-based adaptation” (Table 2). The strategy looks into the climate change impacts and effects from a hazard-centered approach, which emphasizes the geophysical impacts and consequent physical effects, damages, and loss of assets and property caused by natural environmental phenomena and hazards. It does not mention anything about how, when, and why natural hazards turn into disasters for a particular group of people. It does not address the structural factors, i.e., the social, economic, and political aspects of vulnerability. As shown in Table 2, this hazard-centric approach is explicitly reflected in the suggested adaptation and mitigation measures which are mostly top-down and technocratic intervention by nature. However, the strategy mentioned about “social protection for the vulnerable,” but it does not provide any definition or elaboration of attributes of social protection or vulnerability.

Policy Objectives and Strategic Focus

Adaptation to climate change is the major strategic focus of BCCSAP 2009. The thrust of the strategy is on sustainable development, poverty eradication, and increased well-being of all vulnerable groups in society with special emphasis on gender sensitivity. Drawing on the principles of sustainable development, the strategy suggested activities in all four building blocks of the Bali Action Plan – adaptation, mitigation, technology transfer, and adequate and timely flow of

Table 2 Climate change impacts, effects, and suggested interventions in BCCSAP 2009

Climate change context	Resultant impacts	Primary physical effects	Key adaptation and mitigation measures
Cyclones with increased frequency and severity	Higher storm surges	Damage to natural and built environment	Cyclone shelters
Heavier more erratic rainfall in the monsoon seasons	Higher wind speed	Damage to agriculture (crop, livestock, and fisheries)	Forestation
Lower more erratic rainfall in dry seasons	Higher river flow	Scarcity of water and shortage of safe drinking water	Polders
Melting of Himalayan glaciers	Riverbank erosion	Displacement of people	Embankments
Sea level rise	Increased sedimentation in riverbeds	Threat to food security and livelihoods and health	Raised roads and railways
Warmer and more humid weather	Increasing drought and scarcity of drinking water	Over-topping and breaching of embankments	Water management
	Higher river flows in warmer months then reduced flows and increased saline intrusion	Widespread flooding	Flood proofing
	Submergence of low lying coastal areas	Loss of homes and agricultural land into the river	Improved crops and cropping system
	Saline water intrusion into rivers and into groundwater aquifers	Drainage congestion	Possible industrial relocation
	Increased prevalence of disease and disease vectors	Water logging	Early warning system
		Loss of fertility of agricultural land	Health, education, and awareness building
		Displacement of settlements	Communications

Source: Extracted from MOEF (2009, pp. 14, 18, 26)

funds. The main objectives of the strategy are (1) to increase the country's resilience to climate change, (2) to reduce and/or eliminate the risks climate change poses to national development, and (3) to rapidly develop the country following a low-carbon growth path. In general, the strategic focus is broadly pro-poor and responsive to the notion disaster vulnerability. In a consistent manner, the first and second objectives are about resilience and risk reduction with strategic potentially of being a people-centered policy. However, as the strategic focus and objectives are translated into the action plan in terms of mitigation measures and detailed programs, it confirms the hazard-centered and physical intervention-oriented adaptation strategy of the policy as discussed in the next sections.

The Action Plan

The strategy outlines an action plan based on six thematic strategic focus or six pillars: (1) food security and social protection, (2) comprehensive disaster management, (3) infrastructure, (4) research and knowledge management, (5) low-carbon development, and (6) capacity building and institutional strengthening. The action plan provides a 10-year program to build the capacity and resilience of the country to meet the challenge of climate change over the next 20–25 years. The BCCSAP 2009 mentions six key mitigation measures: (a) cyclone shelter, (b) embankments, (c) afforestation, (d) early warning systems, (e) awareness building, and (f) communications. There are 44 programs outlined under six pillars that include the first set of activities which are to be undertaken for adaptation in line with the needs of the communities and the overall development program of Bangladesh.

Owing to the technocratic approach to climate change issues, except the first and the sixth pillars, all the other four pillars reveal top-down macroscale strategies. The thematic strategies hardly outline any bottom-up and people-centered strategic words. The strategies are devoid of significance of the age-old local knowledge and coping strategies and social capacity of the grassroots households or community (Fig. 2).

Most of the adaptation and mitigation measures are physical, immediate effect-centered, short to medium term, and to be achieved through external intervention rather than community-based actions (Table 2). The programs (P) detailed under the six thematic strategies (T) reflect the technocratic nature of the action plan. Except few exceptions, in general, the programs are prescriptive, top-down, and meant more for the government, private, NGOs, and other stakeholders, less for the grassroots community people. The community people are treated as passive actors and left at the receiving end of the program, while other stakeholders are treated as the active players in preparation, implementation, and monitoring of the action plan. Table 3 reveals examples of some programs and actions detailed under the action plan. Comments are included against the programs in support of this argument.

Institutional Environment

It is argued in BCCSAP 2009 that the strategy and action plan were developed through a participatory process involving relevant ministries and agencies, civil society, research organizations, the academia, and business community. However, since the preparation, consultation, and formulation of the strategy, there was no

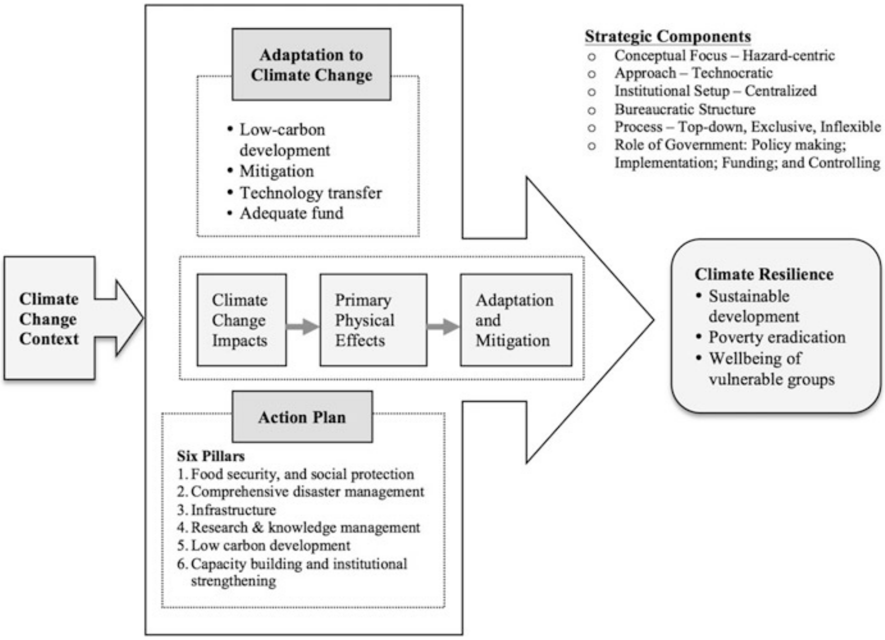

Fig. 2 Strategic framework of BCCSAP 2009 (Source: Diagrammatic interpretation by the authors based on the first five sections of MOEF 2009)

real participation of the grassroots community. The consultations were limited to experts, government officials, selected local government representatives, NGOs, and other stakeholders that hardly allowed for grassroots community participation; reflections of their voice; alternative proposals and strategies for adaptation; or community-based policy preparation.

The institutional setup of the strategy suggests that the action plan will be implemented under the guidance of the National Environment Committee, chaired by the prime minister, and will be coordinated by the Minister of Ministry of Environment and Forests (Fig. 3). The institutional setup reveals a top-down, centralized, rigid environment dominated by the ministers and government officials. It does not elaborate how the high-profile national committees, particularly the "climate change focal point" at different ministries, will delegate administrative power and coordinate with the local government. The policy does not mention any reform for the existing institutional environment, which is not very efficient in dealing with climate change adaptation and mitigation initiatives. Regarding the local level governance, it does not suggest any effective institutional mechanisms for horizontal coordination to deal with inter-sectoral issues across different sectors. This is particularly important for the management of inter-sectoral policy and action plans. There exists an environmental committee at divisional level chaired by the commissioner with representation from different government agencies at division level. However, the committees for the most part are nonfunctional and no

Table 3 Examples of programs designed in a top-down approach

ID	Thematic strategy	Program	Example of action	Authors' comments
T1P7	Food security, social protection, and health	Water and sanitation program for climate vulnerable areas	Investment for additional water supply, adopt deep-set groundwater technology	Community and household-based rainwater harvesting is an important local adaptation strategy already in place which needs to be explored
T3P1	Infrastructure	Repair and maintenance of existing flood embankments	Continuing flood protection by embankments	Should rethink continuing construction of embankments and polders for flood control, as it is detrimental for the natural environmental system. Coastal polders are historic strategic mistake done by the then decision makers in the 1950s, which was a technocratic military solution hostile to the natural environmental system. These types of engineering solutions in coastal belts have already altered the natural deltaic land-water system of coast, resulting in higher riverbed and water logging in lower inland. Should consider alternative land use and spatial planning, and planned resettlement
T3P3	Infrastructure	Repair and maintenance of existing coastal polders	Repair and construct polders based on higher sea level and storm surge	
T3P6	Infrastructure	Adaptation against future cyclones and storm surge	Construct new polders, cyclone shelters	
T4P1	Research and knowledge management	Establishment of center for research, knowledge management, and training on climate change	To increase institutional and human capacity of concerned professionals, government officials	Does not include capacity building of local community, households, and community-based organizations

(*continued*)

Table 3 (continued)

ID	Thematic strategy	Program	Example of action	Authors' comments
T4P4	Research and knowledge management	Monitoring of ecosystem and biodiversity changes and their impacts	Set up monitoring system, report, and recommend adaptation measures	Does not include research and monitoring of cultural and behavioral changes and their impacts on the social systems, which are crucial for building resilient community
T6P3	Capacity building and institutional strengthening	Strengthening human resource capacity	Enhance capacity of key staff of government, private sector organizations, ad NGOs for accessing international and national carbon and climate change funds	Does not include enhancement of local institutions, people, and community-based organization's capacity

Source: Extracted from the Annex of BCCSAP (2009), MOEF (2009, pp. 39–73)

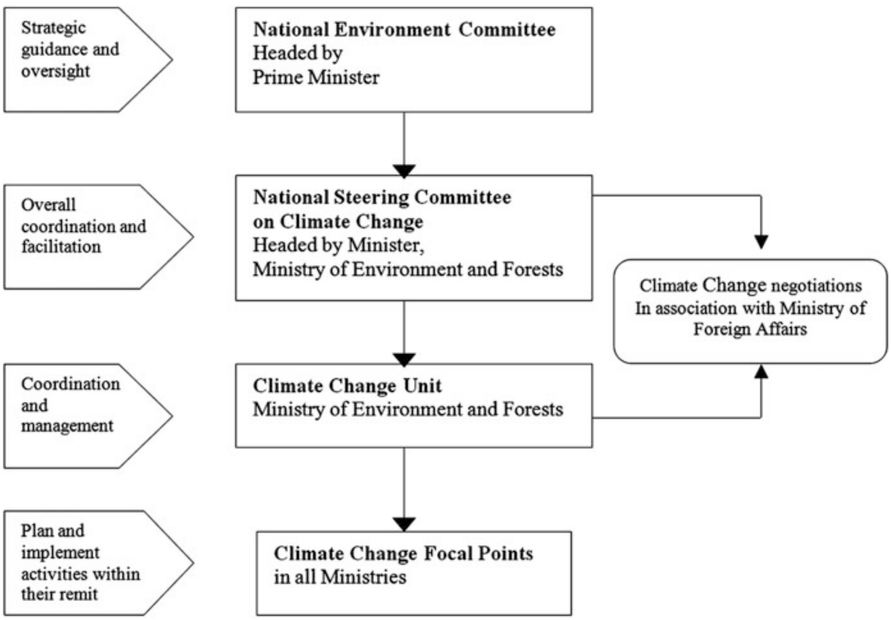

Fig. 3 Institutional setup of climate change action plan (Source: MOEF 2009, p. 30)

such committees exist at lower administrative levels. The suggested institutional setup thus is the reiteration of the existing nondemocratic and bureaucratic governance system. Therefore, risk remains that the same political economy might hinder successful implementation of the policy.

Integrating Disaster Vulnerability in Policy Context: A Conceptual Framework

Climate change is not only an environmental concern but also a development concern for Bangladesh (Parvin and Mostafa 2012). This means that climate change as an issue must come out of the environmental problem to take a center stage as a major development problem created by the unjust structural systems. This requires a paradigm shift in the policy context that would support structural reform with the strategic vision to eradicate social vulnerability of people. However, this type of fundamental shift in policy meets serious resistance from the power elites, policymakers and bureaucrats, and numerous beneficiaries of the prevailing systems. Nonetheless, that resistance is not stronger than the threats of climate change which must have to be addressed not by individual power and wealth but by communal spirit and capacity. With this hypothesis, the study suggests an alternative conceptual framework for the integration of social vulnerability approach in the climate change policy context of Bangladesh (Fig. 4).

Outline of the Conceptual Framework

- *Policy Context*

  The policy should understand the climate change context not merely from a hazard-centered perspective but as a result of dynamic interrelationship among the social, economic, and environmental systems.
- *Policy Objectives*

  The policy objectives should focus more on pro-poor community-driven climate-resilient development targets in place of traditional economic growth-laden development.
- *Approach to Climate Change*

  Climate change issues should be conceived from a people-centered participatory approach instead of technocratic approach.
- *Conceptual Focus*

  The policy environment should be underpinned by the conceptualization of the notion of climate change impacts and adaptation from structural perspective instead of hazard-centered perspective.
- *Strategic Focus*

  The strategic focus should be on “climate change adaptation through eradication of social vulnerability and reduction of structural inequality that results in disaster risks.”

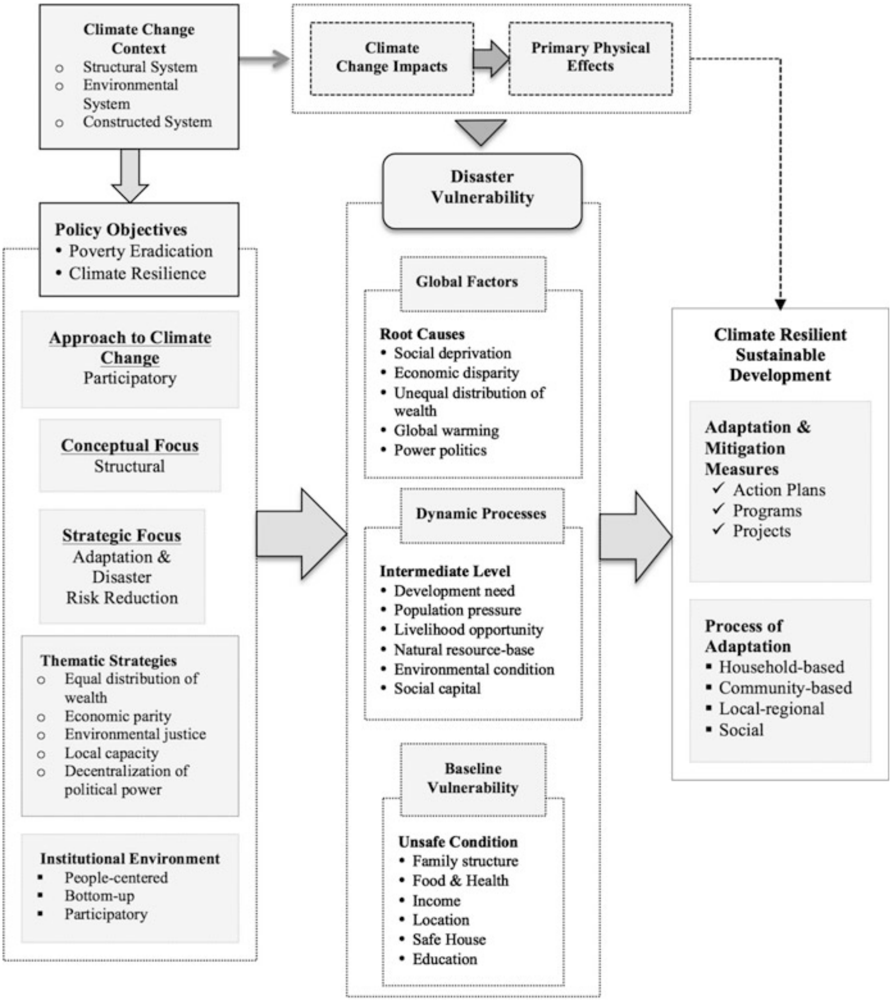

Fig. 4 Conceptual framework for the integration of social vulnerability approach in the climate change policy context of Bangladesh

- *Thematic Strategies*

  The policy should be based on following seven thematic strategies as seven pillars of climate change adaptation plan:

  1. Social-ecological justice – strategies to eradicate the root causes of vulnerability through necessary reform in the social systems such as equal access to assets, infrastructure, and ecological services; re-distribution of safer land; and ensuring food, health, education, and income security
  2. Economic parity – strategies to ensure equal distribution of wealth, diversified livelihood opportunities, and equal access to productive sectoral resources

3. Environmental justice – strategies to ensure environmental protection and biodiversity, prevention of environmental degradation, mitigation of global warming, and environmentally friendly development
4. Local capacity – strategies to research and build on the indigenous knowledge and local adaptation practices and strengthening community capacity learning from their inherent strengths of living with disasters
5. Planned resettlement – strategies to support gradual migration of people living in disaster-prone areas, planned evacuation of settlements from ecologically fragile areas, and long-term guided development of potential destinations (at national, regional, and international level) for the climate-induced migrants
6. Decentralization of political and institutional power – strategies for the development of local government institutions with the objectives of "devolution" and "deconcentration" of decision-making power and creating a community-based enabling institutional environment
7. Comprehensive climate change management – strategies for short-, medium-, and long-term management of climate change impacts; hazard-research, knowledge, and information management; and ensuring sufficient fund raising and management

- *Institutional Environment*

  The institutional structure should be people centered, democratic, and participatory. The governance should be by the people, of the people, and for the people. In place of vertical top-down administration, there should be horizontal, community-based, bottom-up administration where the government's role should be of coordinator, facilitator, and fund provider.

Conclusion

In the backdrop of a social system characterized by a high level of inequality, poverty, and deprivation, climate change is only one aspect of the social vulnerability of grassroots people in Bangladesh. Impacts of climate change therefore adversely affect the capability of the poor and disadvantaged to reduce their vulnerabilities. This implies that any responses to reduce disaster risks should start off with a clear recognition of social vulnerability at every stage of adaptation process. Bangladesh government is fully committed to manage climate change with a vision to eradicate poverty and achieve economic and social well-being for all the people. This will be achieved through a pro-poor climate change strategy, which prioritizes adaptation and disaster risk reduction and also addresses low-carbon development, mitigation, technology transfer, and the mobilization and international provision of adequate finance (MOEF 2009). Notwithstanding the resource constraints, Bangladesh has already developed state-of-the-art warning system and has taken the lead among the LDCs in climate change response in terms of policy initiatives, research, program design, and implementation of adaptation strategies, and this work is continuing. However, Bangladesh is yet to develop context-responsive comprehensive policies that will guide climate change adaptation as an indispensible part of development process in an integrated manner. The critical review of the policy context reveals that existing climate change policies lack in conceptualization of disaster vulnerability as a social phenomenon and, therefore, do not address the structural dynamics of disaster vulnerability adequately. In a country like Bangladesh, where lack-of-development led problems are persistent, there is an urgent need to reform the unequal structural systems through a paradigm shift in the policy context. Climate change impacts in this regard offer an opportunity to formulate policies and adaptation strategies in such a manner that would enable the country to develop resilience not only to climate change but also to poverty and social inequality.

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Enabling Policies for Agricultural Adaptations to Climate Change in Sri Lanka

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Abstract

Climate change has imposed an extra burden on the social and economic challenges faced by Sri Lanka, due to increasing vulnerability of a majority of its people whose livelihoods are dependent on climate-sensitive natural resources, mainly dealing with agriculture. The National Agriculture Policy (NAP) of 2007, National Livestock Development Policy (NLDP) of 2007, and National Fisheries and Aquatic Resources Policy (NFARP) of 2006 are the key policies that govern Sri Lanka’s crops, livestock (including poultry), and fisheries sectors, respectively, under variable and changing climatic conditions. Sri Lanka has taken measures to adapt to climatic risks in these sectors at various levels. The establishment of Climate Change Secretariat of Sri Lanka is a significant step towards integrating and mainstreaming climate change adaptation activities to the development planning of the country. Sri Lanka, being a party to the United Nations Framework Convention on Climate Change (UNFCCC) since 1994, has made considerable attempts in its policy framework and strategic approaches to address the impacts of climate change in crops, livestock, and fisheries sectors, which are directly related to food production. Adaptation to climate change in these three key sectors of Sri Lankan economy is supported by the National Environmental Policy (NEP) of 2003, National Climate Change Policy (NCCP) of 2012, and National Climate Change Adaptation Strategy (NCCAS) 2011–2016. As discussed in detail in this chapter, Sri Lanka has an enabling policy environment in supporting the adaptive strategies and building resilience to climate change. However, given the inherent complexity in adaptation to climate change, the country is facing a challenging situation especially due to the intricacy brought by the institutional coordinating mechanism in the three sectors. A significant level of capacity constraints exists in the sectoral institutes in meeting their mandates to implement policies and strategies related to climate change in Sri Lanka.

Keywords
National policies • Agriculture • Crops • Livestock • Fisheries • Adaptation • Sri Lanka

Introduction

Sri Lanka is located about 80 km southeast to the Indian subcontinent, lying between 5° 55′ and 9° 50′ north latitudes and between 79° 42′ and 81° 53′ east longitudes. The country comprises of a main island and several small islands off the northern end. The mainland has a maximum length of 435 km in the north–south direction and a maximum width of 240 km in the east–west direction. It covers a total area of 65,625 km^2, including 2,900 km^2 of inland water bodies. The island consists of a mountainous area in the south-central part and a vast surrounding coastal plain. The population is estimated to be 20.3 million (Central Bank 2013), and the highest projected population (23.3 million) would be in the year 2046 (Ministry of Environment and Natural Resources 2011). There are 103 natural river basins in Sri Lanka, with a total length of about 4,500 km. In addition, there are a significant number of reservoirs including ancient irrigation tanks and recently constructed multipurpose reservoirs with a total area of 169,941 ha (Ministry of Environment and Natural Resources 2009). Sri Lanka can be divided into 46 agroecological regions based on the amount of monthly rainfall and its distribution, soil type, altitude, terrain, and land use (Punyawardena 2007).

Climate and Climate Change in Sri Lanka

The climatic pattern of Sri Lanka is determined by the generation of monsoonal wind patterns in the surrounding oceans. Four basic seasons exist based on rainfall, namely, the first inter-monsoon (FIM) period from March to April, the southwest monsoon (SWM) period from May to September, the second inter-monsoon (SIM) period during October to November, and the northeast monsoon (NEM) period from December to February. Out of the major climatic parameters, temperature, rainfall, and humidity are of special significance, which can cause a substantial impact on the agricultural productivity of the country. The relative humidity (RH) generally ranges from 70 % to 90 % during morning and 55 % to 80 % during late afternoon depending on the geographical location. Nevertheless, being a tropical country, solar radiation hardly limits the crop growth under general weather conditions. Analysis of climate data has shown that the country's average temperature is significantly increasing at a rate of 0.01–0.03 °C per year (Fernando and Chandrapala 1995; Premalal and Punyawardena 2013). Recent studies have also shown that cumulative annual or seasonal rainfall of major climatic zones in Sri Lanka during the last few decades has not undergone a significant change (Nissanka et al. 2011; Marambe et al. 2012).

Crops, Livestock, and Fisheries Sectors in Sri Lanka

The agriculture sector includes crops, livestock (including poultry), and fisheries as main subsectors. About 33 % of the employed population is involved in agriculture-related activities. Though the contribution of the agriculture sector to the gross domestic production (GDP) is only 11.1 % with an annual growth rate of 5.8 %, this sector plays a vital role in the rural economy (Central Bank 2013). The composition of the agriculture GDP in Sri Lanka as of 2012 is illustrated in Fig. 1.

Sri Lanka is rich in agro-biodiversity (Pushpakumara and Silva 2008) with different rice (dehusked paddy), other cereals, pulses, vegetables, roots and tubers, spices, and fruit varieties. Among them, paddy is the main agricultural crop cultivated in the country, while tea and coconut have the highest contribution to the GDP of the plantation sector (Central Bank 2013). Paddy cultivation has received a greater attention from the ancient times, especially in the dry zone of the country. The paddy sector contributes about 1.3 % to the GDP. The other food crops consisting of coarse grains, condiments, grain legumes, vegetables, tuber crops, and fruit crops contribute to 3.3 % of the GDP. The majority of the other food crops are mainly cultivated in the dry zone of Sri Lanka under rainfed and irrigated conditions. The livestock sector contributes to about 0.8 % of the GDP of Sri Lanka. In the rural economy, livestock species such as cattle, buffalo, goats and pigs, and poultry are reared as an additional source of income, whereas more attention is directed toward crop cultivation. The fisheries sector contributes around 1.8 % to the GDP of the country. Fish products are an important source of protein, providing around 54 % of the animal protein consumed in Sri Lanka (Census and Statistics 2010).

Out of the four rainfall seasons, two consecutive rainy seasons make up the major growing seasons of Sri Lanka, namely, *Yala* and *Maha* seasons. Generally

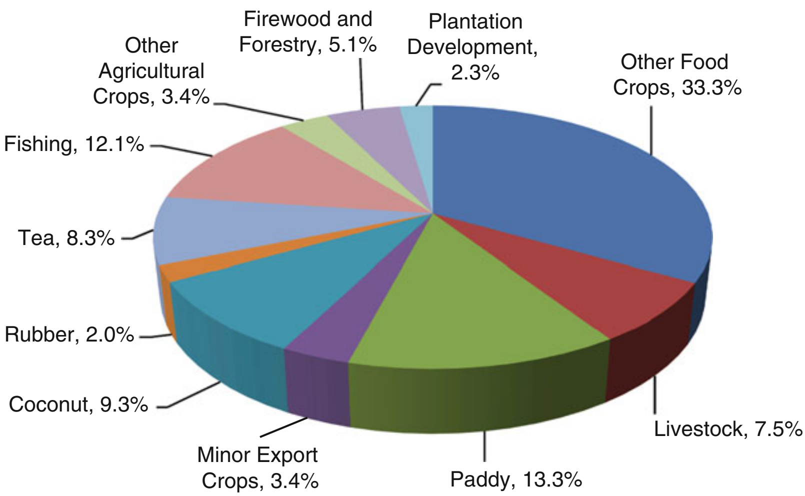

Fig. 1 Composition of the agriculture GDP of Sri Lanka (Source: Central Bank 2013)

Yala season is the combination of FIM and SWM rains. Since SWM rains are effective only over the country's southwestern sector, the length of this season in the rest of the country confines only to 2 months. Hence, the *Yala* season is considered as the minor growing season of the country. The major growing season of the island, *Maha* season, begins with the arrival of SIM rains in October and continues up to late January/February with the NEM rains. In each agroecological region, the traditional and modern farming systems have developed fitting into the local climatic conditions. Thus, the changes in climatic factors such as temperature, rainfall (including rainfall pattern), relative humidity, air temperature, solar radiation, air circulation, and wind are highly linked to the variability observed in the agricultural productivity of the country.

Climate Vulnerabilities and Impacts

Climate change is a crosscutting issue, and it is increasingly recognized as a necessary component of development-oriented decision-making process. In order for development investments to become resilient to anticipated climate change, it is important to understand the nature of vulnerability from a subnational perspective and reflect this variance in development strategies that are formulated at different administrative levels.

The climate vulnerability of Sri Lanka has been assessed considering the major development sectors such as agriculture, water resources, coastal resources, and human health and nutrition, which are the mostly vulnerable sectors in the economy that determine the livelihoods of the people. Apart from these, climate change has already created changes in the dynamics of invasive alien fauna and flora (Marambe et al. 2010), while the national parks situated in the dry zone have already felt the impact of climate changes on the wildlife. Zubair et al. (2005) reported that the seasonal and multiyear climatic anomalies would probably contribute to the human-elephant conflict in Sri Lanka. Climate change has also affected the infrastructure of the country, namely, transport, roadways, and makeshift dwellings.

The two National Communications on Climate Change (Ministry of Forest and Environment 2000; Ministry of Environment and Natural Resources 2011) discuss the effect of climate change on food security with special emphasis on vulnerable groups of Sri Lanka. The Second National Communication (Ministry of Environment and Natural Resources 2011) clearly states that the rural populations in Sri Lanka are exposed to the adverse impacts of climate change as their livelihood is mainly dependent on agriculture, fisheries, and forestry, which are vulnerable to climate change.

Change in the climate temporally and quantitatively would affect the national food supply and livelihoods of the farming community. Seo et al. (2005) identified that the developing countries will be more vulnerable to climatic changes due to being located in hot climatic zones, having a greater fraction of their economies in climate-sensitive sectors (e.g., agriculture), and the economy relies on labor-intensive technologies with fewer adaptation opportunities. However, the climate change impacts on developing countries remain poorly understood as only few studies have successfully measured the effects of climate on the developing economies. Eriyagama et al. (2010) reported that the change in climatic factors has direct impacts on the agricultural production of Sri Lanka. A recent study conducted by Punyawardena et al. (2013) based on 22 physical and socioeconomic parameters that are directly related to the three components of climate change vulnerability, namely, exposure, sensitivity, and adaptive capacity (McCarthy et al. 2001), has revealed that spatial variations of vulnerability of Sri Lanka to climate change vary according to socioeconomic, environmental, and institutional conditions of respective administrative districts. This pattern does not necessarily follow in the most exposed and geographically sensitive districts.

The Climate Change Secretariat of Sri Lanka has mapped the vulnerability of different crops and livestock to drought, flood exposure, and sea-level rise changes with the agroecological zone of the country. The crop and livestock production systems of dry and intermediate zones of Sri Lanka are more vulnerable for the impacts of the climate change. The impacts of climate change and the vulnerability of the agriculture sector are summarized in Tables 1 and 2.

Table 1 Major impacts of climate change on the agriculture sector in Sri Lanka

<table>
<tr><th>Climate change</th><th>Tea</th><th>Rubber</th><th>Coconut</th><th>Paddy</th></tr>
<tr><td>Temperature increase</td><td>Affects quality parameters of high-grown tea</td><td>Not known</td><td>Affects pollen development and viability; number of nuts per bunch</td><td>Affects pollen development causing sterility and empty grains</td></tr>
<tr><td rowspan="2">Erratic rainfall – too high</td><td>Affects harvesting</td><td rowspan="2">Reduce days available for tapping</td><td rowspan="2">Not known</td><td rowspan="2">Affects land preparation and sowing and needs no rains at harvesting</td></tr>
<tr><td>Enhances soil erosion</td></tr>
<tr><td>Erratic rainfall – too low</td><td>Affects yield</td><td>Not known</td><td>More than two consecutive months without rain is detrimental</td><td>Affects land preparation. Insufficient soil moisture affects growth</td></tr>
<tr><td>Sea-level rise</td><td>Not known</td><td>Not known</td><td>Salinization of coastal coconut lands</td><td>Loss of paddy lands in coastal areas; salinization of soil and irrigation water</td></tr>
<tr><td rowspan="2">Climate dependency</td><td>Entirely rainfed</td><td>Entirely rainfed</td><td>Entirely rainfed</td><td rowspan="2">Rainfed with supplementary irrigation</td></tr>
<tr><td>Low temperature at high elevations affects quality</td><td>If less than 500 mm affects yield; non-rainy days for tapping</td><td>Annual rainfall not less than 1,500 mm</td></tr>
</table>

Table 2 Major impacts of climate change on livestock and fisheries sectors in Sri Lanka

Climate change	Livestock	Fisheries
Temperature increase	Affects the fertility, influences the quality of feeds available for ruminants, and changes the disease and parasitic occurrence	Affects breeding habits and levels of production and influences the quantity and quality of feed available
Erratic rainfall – too high	Threat to animal life due to floods	Loss of habitat in inland water bodies
Erratic rainfall – too low	Threat to animal life due to water and food scarcity	Threat to animal life in inland water bodies
Sea-level rise	Loss of habitat	Loss of habitat
Climate dependency	Direct effect on fertility and indirect effect on production	Direct effect on breeding and indirect effect on production

The Global Context of Climate Change, Regional Initiatives, and National Commitments

The Global Context

In response to the warnings issued by scientists in the 1970s on the impact of enhanced natural greenhouse gas effect, causing the Earth to become warmer if the pattern of emission of greenhouse gases (GHGs) continues, the Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to develop an international policy instrument to address the issue of global warming, leading to the development of the UNFCCC. The UNFCCC was adopted at the Rio Summit of the United Nations (UN) in 1992 with the objective of stabilizing the atmospheric GHG concentration at a level that will prevent dangerous human interferences with the climate system. Since then, the parties have continued to negotiate in order to agree on decisions and conclusions that will reduce global greenhouse gas emissions. Adoption of the Kyoto Protocol in 1997 is a landmark event in such negotiations where the developed countries collectively committed to reduce emissions of six key greenhouse gases at least by 5.2 % from their total GHG emissions recorded in 1990, during the first commitment period 2008–2012 (Ministry of Environment 2006).

Regional Initiatives

The South Asian Association for Regional Cooperation (SAARC; comprises of eight countries, namely, Afghanistan, Bangladesh, India, Maldives, Pakistan, Nepal, Myanmar, and Sri Lanka) has moved along with the global and other regional mandates in tackling issues related to climate change (http://www.saarc-sec.org/). The SAARC has signed a memorandum of understanding with the South Asia Co-operative Environment Programme (SACEP; July 2004), United Nations Environment Programme (UNEP; June 2007), and the United Nations International Strategy for Disaster Reduction (UNISDR; September 2008) and was accredited as an observer to the UNFCCC process at the 16th Conference of the Parties (COP 16) in 2010.

Since 1987, SAARC has reiterated the need to strengthen and intensify regional cooperation to preserve, protect, and manage the diverse and fragile ecosystems of the region including the need to address the challenges posed by climate change and natural disasters. Accordingly, a Technical Committee on Environment (TCE) was established in 1992 to examine the recommendations of the regional studies to identify measures for immediate action and decide on modalities for their implementation. The SAARC countries have adopted common positions at various international negotiations related to environment and climate change. The TCE has been entrusted with the coordination and monitoring of implementation of the 1997 SAARC Environment Action Plan and SAARC Action Plan on Climate Change (July 2008) under Article VI of the SAARC Charter (http://saarc-sec.org/areaofcooperation/cat-detail.php?Cat_id=54). The SAARC also has established the SAARC Coastal Zone Management Centre (SCZMC) in 2004 to promote cooperation in planning, management, and sustainable development of coastal zones, including research, training, and awareness in the region (http://www.sczmc.org/).

The SAARC Environment Action Plan has been adopted by the Third Meeting of SAARC Environment Ministers (Male, 15–16 October 1997), which have identified some of the key concerns of member states and set out the parameters and modalities for regional cooperation. A SAARC Convention on Cooperation on Environment as stipulated under the Item 17 (Legal Framework) of the Action Plan was signed during the 16th SAARC Summit (Thimphu, 28–29 April 2010) and was entered into force after it has been ratified by all member states. The key initiatives and proposals in the Thimphu Summit in 2010 are as follows: (a) establishing an Intergovernmental Expert Group on Climate Change to develop clear policy direction and guidance for regional cooperation; (b) exploring the feasibility of a SAARC mechanism that will provide financial capital for low-carbon technology and renewable energy projects; (c) strengthening the understanding of shared water bodies in the region through a marine initiative; (d) establishing the Intergovernmental Mountain Initiative to study mountain ecosystems and glaciers and their contribution to livelihoods and sustainable development; (e) establishing the Intergovernmental Monsoon Initiative on the evolving pattern of monsoons to assess vulnerability due to climate change; (f) commissioning a SAARC Intergovernmental Climate-Related Disasters Initiative on the integration of climate change adaptation (CCA) with disaster risk reduction (DRR); (g) establishing institutional linkages among national institutions in the region to facilitate sharing of knowledge and capacity building programs in climate change; (h) enhancing cooperation in the energy sector to facilitate energy trade and development of efficient conventional and renewable energy sources including hydropower; (i) preparing an action plan on energy conservation by the SAARC Energy Centre (SEC); and (j) creating a web portal on energy conservation for exchange of information and sharing of best practices among SAARC member states.

The SAARC Action Plan on Climate Change (2009–2011; http://saarc-sdmc.nic.in/pdf/publications/climate/chapter-2.pdf) has identified seven thematic areas of cooperation in relation to climate change, namely, adaptation, mitigation, technology transfer, finance and investment, education and awareness, management of impacts and risks, and capacity building for international negotiations. Though there is no direct identification of agriculture-related sectors in this action plan, the issues have been embedded in areas such as adaptation and management of impact. However, SAARC has now formed a focal group to identify the adaptation measures to minimize the impacts of climate change on agriculture. The action plan lists the areas of capacity building for Clean Development Mechanism (CDM) projects: exchange of information on disaster preparedness and extreme events, exchange of meteorological data, capacity building and exchange of information on climate change impacts (e.g., sea-level rise, glacial melting, biodiversity, and forestry), and mutual consultation in international negotiation process as the priorities.

The SAARC Disaster Management Centre (SDMC; http://saarc-sdmc.nic.in/index.asp) was established in New Delhi, India, in 2006 to provide policy advice and facilitate capacity building including strategic learning, research, training, system development, expertise promotion, and exchange of information for effective DRR and management. The mandate of the center has been expanded to include the development of a Natural Disaster Rapid Response Mechanism. Road maps have been developed to include coastal and marine risk management plan, community-based disaster risk management, application of science and technology in DRR, and urban risk management, drought management, and flood risk management in South Asia.

Apart from the SAARC initiative, there are two regional neighboring corporations in Asia that have strong and committed efforts in adapting and mitigating global climate change. Both Central Asia (CA) and Association of Southeast Asian Nations (ASEAN; http://www.asean.org/) regional corporations have climate change response policies and environmental, legal, and regulatory framework for meeting their commitments under the UNFCCC. The details of these corporations on climate change mitigation policy and activity frameworks are not discussed in this chapter.

National Commitments

Sri Lanka ratified the UNFCCC on 23 November 1993 and entered into force on 21 March 1994 and was among the first 50 countries to have ratified the convention. This was followed by becoming a signatory to the Montreal Protocol (on substances that deplete the ozone layer) and the Kyoto Protocol, which commits countries, i.e., mainly Annex I parties, to reduce their collective emissions of greenhouse gases.

Even though Sri Lanka is a non-Annex I country with a per capita emission of greenhouse gases (GHGs) as low as 0.6 t of CO_2 equivalent per year and the total emissions from all sectors at 20,794 $GgCO_2$ equivalents (Ministry of Environment and Natural Resources 2010), it is the objective of the Government of Sri Lanka to encourage and facilitate investments in climate-friendly development activities while fulfilling the country obligations and contributing to the ultimate objective of the UNFCCC.

Sri Lanka has established a Climate Change Secretariat (CCS) within the Ministry of Environment and Renewable Energy (ME&RE) to facilitate, formulate, and implement projects and programs at the national level with regard to climate change. The GHG inventory for the year 2000 has been prepared (Ministry of Environment and Natural Resources 2011) and an update is currently being done. The Centre for Climate Change Studies (CCCS) was established in 2000 (http://www.meteo.slt.lk/cccs.html) under the Department of Meteorology of Sri Lanka to conduct research, monitor climate change, and provide the general public with current information on climate change and allied issues. The Initial National Communication on Climate Change under the UNFCCC was prepared in 2000 (Ministry of Forest and Environment 2000), which indicated sectors that are most vulnerable to climate change and subsequent impacts, the sectors that mostly contribute to climate change, and the required mitigation options and adaptation responses, while the Second National Communication was completed in 2010 (Ministry of Environment and Natural Resources 2011). The national capacity needs to implement the UNFCCC have also been identified (Ministry of Environment and Natural Resources 2007a).

The Policies and Legislations Related to Climate Change and Relevant Sectors in Sri Lanka

Being a crosscutting phenomenon, the climate change issues have been addressed in different sectoral policies in Sri Lanka. These policies have addressed the adaptive and migratory capacities of the country at different priority levels.

National Environmental Policy (NEP) of 2003

The National Environmental Policy (NEP) of 2003 (http://www.climatechange.lk/ccs_index.html) provides the direction and framework for managing and caring for the environment in Sri Lanka and spells out the directions needed in relation to the basic natural resources such as land, water, atmosphere, and biological diversity and the environmental strategies to be followed by key economic sectors. Under the segment on land resource management, the NEP recognizes the need for providing interventions to increase agricultural productivity and sound agricultural practices in all cultivated land in the island, especially where land degradation is the most serious issue. The NEP also states that the environmental changes that affect land resources will be monitored and the real costs of environmental damage from the misuse of land will continually be assessed, on the basis of recognized priorities. Article 2.2.10 of the NEP on reducing the risk of climate change states that "The risks of climate change will be managed by implementing adaptive strategies that minimize the impact of climate change on both the people, and the economy, of Sri Lanka." The policy directives identified in NEP to accomplish this are as follows: (a) review the effect of climate change on Sri Lanka through the development of impact scenarios and response strategies, (b) develop policy scenarios for the use of CDM and its application for Sri Lanka, (c) evaluate the needs to enter into future potential trading system for carbon reduction including the necessity for clear and secure property rights or entitlements to land and carbon, and (d) develop an information database through the ministry in charge of the environment.

The National Climate Change Policy (NCCP) of 2012

The National Climate Change Policy (NCCP) of 2012 is the overarching policy dedicated to address the issues of climate change in Sri Lanka. Paragraph 14 of Article 27 in Chapter 6 (Directive Principles of State Policy and Fundamental Duties) of the Constitution (1978) of Democratic Socialist Republic of Sri Lanka clearly states that "the state shall protect, preserve and improve the environment for the benefit of the community." This governs the activities of all state, private sector and nongovernmental organizations, and individuals in protecting the environment of the country. Besides that, the NEP of 2003 carries the Policy Statement 4 indicating that "Environmental management systems will be encouraged to be flexible so as to adapt to changing situations (e.g., climate change, invasive species and living genetically-modified organisms) and adopt the precautionary principle as priority areas requiring action." In addition, the National Environmental Outlook (Ministry of Environment and Natural Resources 2009), the Caring for the Environment II 2008–2012 (Marambe and Silva 2008), the Addendum to the Biodiversity Conservation Action Plan (Ministry of Environment and Natural Resources 2007b), the Initial and Second National Communications to UNFCCC (Ministry of Forestry and Environment 2000; Ministry of Environment and Natural Resources 2011), and the National Action Plan for the *Haritha Lanka* (Green Lanka) Programme (National Council for Sustainable Development 2009) highlight the need to address climate change issues as priority interventions.

The Initial (Ministry of Forestry and Environment 2000) and Second (Ministry of Environment and Natural Resources 2011) National Communications to the UNFCCC presented by the Sri Lankan government have identified agriculture, water resources, and public health as the most affected sectors due to climate change. While Sri Lanka is vulnerable to many impacts of climate change, the island nation's contribution to GHG emissions is relatively low when compared even with other developing countries, and hence, adaptation has naturally been a priority in climate change policy in Sri Lanka. The NCCP clearly states that while taking adaptive measures as the priority, Sri Lanka will actively be involved in the global efforts to minimize the greenhouse gas emissions within the framework of sustainable development and principles enshrined in the UNFCCC and the Kyoto Protocol.

The NCCP of Sri Lanka provides guidance and directions for all the stakeholders to address the adverse impacts of climate change efficiently and effectively. Accordingly, the NCCP has included statements related to periodic assessment of vulnerability to adverse impacts of climate change in the socioeconomic and environmental sectors. This information will be highly useful in adaptation to adverse impacts in short as well as long term and mitigation, which are the two main pathways to minimize the adverse impacts of climate change. The NCCP of Sri Lanka has been formulated with the primary goal of "Adaptation to and mitigation of climate change impacts within the framework of sustainable development," with seven objectives, namely, (1) sensitize and make aware the communities periodically on the country's vulnerability to climate change; (2) take adaptive measures to avoid/minimize adverse impacts of climate change to the people, their livelihoods, and ecosystems; (3) mitigate greenhouse gas emissions in the path of sustainable development; (4) promote sustainable consumption and production; (5) enhance knowledge on the multifaceted issues related to climate change in the society and build their capacity to make prudent choices in decision making; (6) develop the country's capacity to address the impacts of climate change effectively and efficiently; and (7) mainstream and integrate climate change issues in the national development process.

The NCCP contains broad policy statements under the thematic areas of vulnerability, adaptation, mitigation, sustainable consumption and production, knowledge management, and general statements. As the NCCP is the key policy directive in relation to climate change, it links to the sectoral policies. The key issues in relation to crops, livestock, and fisheries are directly addressed under the themes of adaptation and mitigation and indirectly addressed in themes on sustainable consumption and production, knowledge management, and general areas. Table 3 provides the summary of those areas addressed in NCCP.

National Climate Change Adaptation Strategy for Sri Lanka (2011–2016)

The National Climate Change Adaptation Strategy (NCCAS) for Sri Lanka (2011–2016; Ministry of Environment and Natural Resources 2010) has been developed while accepting the fact that Sri Lanka is not a significant contributor to global warming. However, being an island nation, it is vulnerable to the impacts of climate change mainly due to the increases in the frequency and intensity of disasters such as droughts, floods and landslides, variability in climate, and sea-level rise.

The adaptation strategies in relation to agriculture are entrusted mainly under the thematic area of "Minimize Climate Impacts on Food Security." In addition, the plantation sector has been addressed under "Improve Climate Resilience of Key Economic Drivers" as the plantation agriculture is more of an economic activity. The adaptation strategy has followed an integrated approach to minimize the

Table 3 Issues related to agriculture (crops), livestock, and fisheries sectors addressed in the NCCP

Thematic area in NCCP	Issues related to agriculture, livestock, and fisheries
Direct approach	
Adaptation (food production and security)	Take timely action to address the adverse impacts on crop and animal production and fisheries sectors due to climate change and to minimize the impacts on food production and to ensure food security
	Encourage climate resilient, environmentally friendly, and appropriate innovative technologies while recognizing and promoting the utilization of appropriate traditional knowledge and practices in food production
Adaptation (conservation of water resources and biodiversity)	Promote integrated watershed and water resource management and efficient water use through technologies and behaviors adaptive to changing weather patterns and trends
Mitigation (agriculture and livestock)	Encourage environmentally sound and socially acceptable agriculture and livestock practices within the framework of sustainable development
	Promote appropriate innovative technologies while encouraging the utilization of appropriate traditional knowledge and practices
Indirect approach	
Sustainable consumption and management	Promote sustainable consumption and production considering the family as the center of focus to ensure wide dissemination of environment-friendly lifestyles and practices in the path of sustainable development
Knowledge management	Adopt multiple approaches to enhance knowledge, skills, and positive attitudes of different stakeholders at all levels to address multifaceted, current, and emerging issues of climate change
	Facilitate and promote the availability, accessibility, and sharing of climate change-related information across all sectors at all levels
General statements (institutional coordination)	Develop and strengthen an interinstitutional coordinating, collaborating, and monitoring mechanism for effective implementation of the activities related to climate change at national, provincial, district, and divisional levels under the National Focal Point to the United Nations Climate Change Multilateral Agreements

Source: http://www.climatechange.lk/policy.html

climate change impacts on food security involving irrigation, crops, livestock, fisheries, nutrition (health), and environment sectors as part of the initiative to ensure Sri Lanka's national interests are adapted to be resilient to potential climate change-induced risks. Table 4 summarizes the adaptive strategies related to the crops and livestock sectors in NCCAS. The adaptation strategies for the fisheries sector have been addressed under the thematic area of "Safeguard Natural

Table 4 The adaptive strategies related to agriculture (crops) and livestock

Adaptation strategy	Priority adaptive measures
1. Ensure ability to meet food production and nutrition demand	(i) Increase awareness on alternative options to meet nutrition requirements
	(ii) Improve weather forecasting and information dissemination
	(iii) Ensure easy access to seed stock alternatives to counter rainfall variability
	(iv) Research climate impacts/adaptive measures for the agriculture, livestock, and fisheries sectors
	(v) Conserve genetic resources for future crop and livestock improvement
2. Ensure adequate water availability for agriculture	(i) Promote water-efficient farming methods and crops to improve water productivity
	(ii) Improve maintenance of existing tanks and reservoirs including their watersheds and catchments
	(iii) Adopt and promote the principles of Integrated Water Resources Management (IWRM)
	(iv) Construct new reservoirs and trans-basin diversions to meet demand
3. Mitigate food security-related socioeconomic impacts	(i) Encourage risk transfer methods such as insurance
	(ii) Research climate impacts on long-term food security and agriculture value chain
	(iii) Identify and help vulnerable fishing communities to adapt or relocate
4. Increase awareness and mobilize communities for climate change adaptation	(i) Increase awareness on climate impacts on food security and on the potential adaptive measures
	(ii) Pilot test and scale up community-level agriculture/livestock/fisheries adaptation models
	(iii) Improve utilization of field-level coordination mechanisms and civil society organizations
	(iv) Promote risk transfer initiatives
5. Minimize impacts of climate change on the plantation sector	(i) Research climate impacts and adaptive measures in plantation subsectors
	(ii) Pilot test and scale up subsector-specific adaptation measures
	(iii) Evaluate and exploit potential productivity benefits due to climate change

Source: Ministry of Environment and Natural Resources (2010)

Resources and Biodiversity from Climate Change Impacts." Since this thematic area is commonly addressing the broad environmental issues, the strategies are mostly crosscutting. However, there are two strategies listed under this theme, which are directly related to the inland fisheries and coastal sector as given in Table 5.

Table 5 The adaptive strategies related to fisheries and wetlands

Adaptation strategy	Priority adaptive measures
1. Enhance the resilience of coastal and marine ecosystems and associated vulnerable species	(i) Promote integrated coastal resource management, particularly at Special Area Management (SAM) sites
	(ii) Restore and rehabilitate degraded coastal ecosystems and depleted coastal species
2. Enhance climate change resilience of natural inland wetlands and associated species	(i) Protect marshes/flood retention areas in urban areas and limit land conversion
	(ii) Prevent discharge of industrial effluents and solid waste into inland wetlands
	(iii) Control and manage saltwater intrusion into coastal freshwater wetlands
	(iv) Strengthen coordination and streamline management of wetlands across relevant agencies

Source: Ministry of Environment and Natural Resources (2010)

Though the NCCAS is supported with comprehensive sectoral analysis under different thrust areas related to food security, agriculture, livestock, and fisheries, it suffers with a serious lapse in two important areas, namely, energy and health. While the energy sector is completely missing in the priority strategic thrust areas, the health sector has not been adequately addressed in NCCAS probably due to the overemphasis on production aspects. The proposed strategic interventions and implementation strategies for the priority thrust areas in the NCCAS (Ministry of Environment and Natural Resources 2010) are summarized in Table 6.

The National Adaptation Plan (NAP)

Sri Lanka is currently in the process of developing the national adaptation plan (NAP) according to the adaptation strategies laid down to tackle variable climatic conditions.

Other Policies and Actions Related to Climate Change

The national overarching policy of Sri Lanka, *Mahinda Chintana*, Vision for the Future (MFP 2010), envisages an agricultural renaissance and spells out activities to develop the agriculture (crops), livestock, and fisheries sectors and to ensure future food security. Likewise, the *Mahinda Chintana* 10-year Horizon Development Framework 2006–2016 (Ministry of Finance and Planning 2006) provides commitment for the rehabilitation of degraded agricultural lands, establishment of a early warning system or drought and strengthening drought relief, strengthening rainwater harvesting systems, promotion of sustainable agriculture, and adoption of an integrated management system for the land resource, among the many aspects of

Table 6 Strategic interventions for climate change adaptation

Identified area of adaptation	Adaptation actions	Responsible agencies
1. Minimize climate change impacts on food security		
Ensure ability to meet food production and nutrition demand	(i) Prioritization of nutritional issues expected to exacerbate with climate change	Department of Agriculture (DOA)
	(ii) Implementation of awareness program to different population categories	Department of Meteorology (DOM)
	(iii) Empowerment of women in poor farming communities in sustaining household-level food security and nutrition	Department of Health (DOH)
	(iv) Adopting new/improved forecasting technology	Disaster Management Centre (DMC)
	(v) Increasing the technical capacity on forecasting	DOA
	(vi) Development of information dissemination mechanism	DOM
		Department of Irrigation (DOI)
		Department of Agrarian Development (DOAD)
	(vii) Implementation of community-level seed stock program	DOA
	(viii) Technical capacity building for community on seed stock	DOAD
		Community-based organizations (CBOs)
	(ix) Update gene banks to address needs of climate change	DOA
	(x) Identification and protection of germplasm conservation areas	Department of Export Agriculture (DOEA)
		Tea Research Institute (TRI)
		Coconut Research Institute (CRI)
		Rubber Research Institute (RRI)
		Sugarcane Research Institute (SRI)
		Department of Animal Production and Health (DAPH)
		National Aquatic Resources Research and Development Agency (NARA)
		Veterinary Research Institute (VRI)
		CBOs

(*continued*)

Table 6 (continued)

Identified area of adaptation	Adaptation actions	Responsible agencies
Ensure adequate water availability for agriculture	(i) Programs for promotion of water-efficient farming techniques	DOA
		DOI
		DOAD
		CBOs
	(ii) Assessing the maintenance levels of tanks, reservoirs, and irrigation systems	DOI
	(iii) Implementation of renovation and maintenance of those systems	Mahaweli Development Authority of Sri Lanka (MDASL)
	(iv) Development and adaptation of water resource management plan for Sri Lanka	DOA
	(v) Implementation of trans-basin diversion activities	CBOs
	(vi) Assessment of future water requirements	
	(vii) Assessment of the need for new reservoirs	
Mitigate food security-related socioeconomic impacts	(i) Introduction of insurance schemes	DOA
	(ii) Identify the components in the value chain system	DAPH
	(iii) Identification of alternative livelihood activities	NARA
	(iv) Identification and relocation of highly vulnerable communities	Insurance companies
Increase awareness and mobilize communities for climate change adaptation	(i) Develop and implement of national information, education, and communication strategy	All line ministries
		Ministries of Education (MOE)
		Ministry of Higher Education (MOHE)
		Media
2. Safeguard natural resources and biodiversity from climate change impacts		
Enhance the resilience of coastal and marine ecosystems and associated vulnerable species	(i) Facilitate the implementation of sensitive area management activities	Coast Conservation Department (CCD)
	(ii) Rehabilitation of key coastal ecosystems	NARA

(*continued*)

Table 6 (continued)

Identified area of adaptation	Adaptation actions	Responsible agencies
Enhance climate resilience of natural inland wetlands and associated species	(i) Regulate and manage urban wetlands	Urban Development Authority (UDA)
		Central Environmental Authority (CEA)
		Local government units
		CBOs, nongovernmental organizations (NGOs)
	(ii) Development of urban wetlands for different purposes such as recreation	DOI
	(iii) Development of cost-effective purification programs for release of effluent	Ministry of Environment and Renewable Energy (ME&RE)
	(iv) Avoid the water body pollution by development of waste processing program and guidelines for waste disposal	CEA
	(v) Monitoring the water flow at river basins	
	(vi) Controlling of sand mining	
	(vii) Establishment and monitoring of coordination mechanism for the activities of coastal and marine ecosystems and inland water bodies	

Source: updated from Ministry of Environment and Natural Resources (2010)

work to be undertaken to conserve and sustainable use of land in the country. Hence, *Mahinda Chintana* focuses on majority of the issues faced by Sri Lanka related to environment and climate change.

The National Council for Sustainable Development (NCSD) was established in Sri Lanka under the Presidential Secretariat in 2009. The NCSD is chaired by H.E. the President of Sri Lanka with the purpose of seeking a successful blend of the best of modern science and the richness of traditional knowledge for natural resource management and sustainable use, facing the major challenges of climate change and protection of the environment. The NCSD was instrumental in ensuring government policies on environment, and climate change has been translated into action through "Green Lanka for Sustainable Future" (Action Plan for *Haritha Lanka* Programme; National Council for Sustainable Development 2009) and also further entrust stating that "Sri Lanka abides by the global treaties and agreement on environmental and climatic change and will strengthen Sri Lanka's tie with the UN Agencies." Ten missions included in the action plan are (1) clean air; (2) saving the fauna, flora, and ecosystems; (3) meeting the challenge of climate change; (4) wise use of the coastal belt and sea around; (5) responsible use of the land resources; (6) doing away with the dumps; (7) water for all and always; (8) green cities for health and prosperity; (9) greening the industries; and (10) knowledge for the right choice. The Action Plan for *Haritha Lanka* Programme directly addresses climate change through its Mission 3 focusing on establishing food security in the face of climate change threats. The program also indirectly supports measures needed for adaptation in the crops and livestock sectors through Missions 5 (land) and 4 and 7 (water). This Action Plan has short-term, medium-term, and long-term targets spanning 2009–2016 that are relevant for adaptation to climate change.

The National Policy on Air Quality Management of 2000 and the Draft National Policy on Clean Development Mechanism (NPCDM) are two policy and planning instruments, which directly address climate change in Sri Lanka but with no direct reference to the crops, livestock, and fisheries sectors, as they deal especially on the mitigation. However, the NPCDM has indirect implications on those three sectors. The NPCDM is in total compliance with and complementary to the Sri Lanka Strategy on Sustainable Development (Ministry of Environment and Natural Resources 2007c) and the National Action Plan for *Haritha Lanka* Programme of Sri Lanka. The Ministry of Environment, while recognizing the need to embark on CDM activities, has also established two study centers at the University of Peradeniya, Sri Lanka (agriculture and forestry), and at the University of Moratuwa, Sri Lanka (transport and industry), to ensure that there will be continuous interventions and input from the researchers and academia on implementing the CDM projects.

In light of the increasing impact of climate change and the need for future preparedness, the Ministry of Disaster Management and Human Rights (as the leading ministry) and the Disaster Management Centre (DMC) (as the national-level agency) have been mandated to formulate national- and local-level disaster risk management programs and aligning them with the sectoral development programs. In addition, an intragovernmental network has been established with the assistance from Japan International Cooperation Agency (JICA) to connect the Department of Irrigation (DOI), National Building Research Organization (NBRO), Department of Meteorology (DOM), DMC, Police Communications, Media Networks, and seven district offices that are most vulnerable to disasters. This network is expected to facilitate the sharing of GIS maps and other data to better coordinate and manage response activities.

Being cognizant of the irreversible impacts of climate change on the ecosystems and development programs of Sri Lanka, in 2006, the Cabinet of Ministers of the Sri Lankan government directed all government agencies to undergo a Strategic Environmental Assessment (SEA) for all policies, plans, and programs prior to their implementation. The Central Environmental Authority (CEA) of Sri Lanka has carried out SEAs for Trincomalee Development Plan (Eastern Province) and Greater Hambantota Development Plan (Southern Province) and for the Northern

Province Development Program (http://www.isea.lk), while the Sri Lanka Tourism Development Authority (SLTDA) has completed two SEAs for tourism development in the Dedduwa Lake area (Southern Province) and in Kalpitiya area (Northwestern Province). The SEA activities are expected to fine-tune the development programs in Sri Lanka while incorporating environmental concerns to them. The SEAs for Gampaha District (Western Province) and Uva Province are currently being conducted.

The sectoral policies and legislations governing the crops, livestock, and fisheries sectors of Sri Lanka play a crucial role in embedding the climate change concerns in plans and programs implemented under respective sectors. The linkages of these policies in relation to climate change concerns of the country are highlighted below.

Key Development Policies That Govern the Crops, Livestock, and Fisheries Sectors

The National Agriculture Policy (NAP) of 2007

The National Agriculture Policy (NAP) of 2007 deals with food and export agricultural crops and floriculture with the aim of solving problems in these sectors and facilitating their rapid growth. The objectives stipulated in the NAP have been designed to meet the basic needs of the farming community in terms of food security and nutrition and enhanced employment opportunities and income generation by the adoption of technically feasible, socially acceptable, economically viable, and environmentally friendly agricultural production technologies, marketing, and related strategies. The policy includes promoting agricultural production, seeds and planting materials, fertilizers, pesticides, agricultural machinery, postharvest technology, irrigation and water management, land use, soil conservation, traditional agricultural crops, home gardening, and agricultural research. It also deals with providing agricultural credit, agricultural insurance, and agricultural extension and education and promoting marketing, agro-based industries, investments in agriculture, institutional development, sharing of plant genetic resources, and youth involvement in agriculture.

The key issues promoted in relation to climate change in the NAP are (a) production and utilization of organic and bio-fertilizers to gradually reduce the use of chemical fertilizers through Integrated Plant Nutrition Systems (IPNS); (b) minimizing the use of synthetic pesticides through promoting biopesticides and Integrated Pest Management (IPM); (c) conservation of water resources, efficient water management, and soil moisture retention techniques; (d) prevention of water pollution from agriculture; (e) adhering to the National Land Use Policy when allocating land for cultivation purposes; (f) land conservation within watershed areas; (g) enforcing the provisions of the Soil Conservation Act; (h) conservation of traditional agricultural crops and methodologies relating to organic farming, pest control, preservation and processing of food for nutritional and medicinal purposes, and facilitation of the exchange of such knowledge among the farming community; and (i) home gardening and urban agriculture to enhance household nutrition and income.

The National Livestock Development Policy (NLDP) of 2007

The National Livestock Development Policy (NLDP) of 2007 deals with developing the dairy and poultry subsectors and animal feed resources of Sri Lanka. The dairy sector is regarded as the priority for public sector investment in livestock development in the country. There is no direct government involvement or support in the meat subsector, but private sector activities are permitted, and the government takes responsibility for ensuring public health safeguards and quality standards in the meat industry. The goals and targets of NLDP are as follows: (a) the achievement of sustainable and equitable economic and social benefits to livestock farmers; (b) increasing the supplies of domestic livestock produce at competitive prices to the consumers; (c) achieve increased self-reliance of at least 50 % in domestic milk by 2015; (d) double the current domestic production of poultry products by 2015; and (e) domestic livestock products to be competitive with the imported livestock products. Though there is no explicit reference to climate change scenario in the NLDP, the achievement of the objectives of the policy could only be realized by being cognizant of the variable and changing climate in Sri Lanka, which will be facilitated by the NCCP.

The National Fisheries and Aquatic Resources Policy (NFARP) of 2006

The National Fisheries and Aquatic Resources Policy (NFARP) of 2006 promotes increasing the production of marine and inland fisheries and conserving the resource; development of aquaculture; improvement of infrastructure facilities for fisheries, including fishery harbors, product marketing, research, and use of nonliving aquatic resources; extension and training; uplifting of the socioeconomic status of the fisher community and rehabilitation of fisheries affected by the conflict and the tsunami; institutional and legal framework; and international cooperation and conservation of the environment. The objectives of the NFARP are to (a) improve nutritional status and food security of the people by increasing the national fish production, (b) minimize postharvest losses and improve quality and safety of fish products to acceptable standards, (c) increase employment opportunities in fisheries and aquatic resource-related industries and improve the socioeconomic status of the fisher community, (d) increase foreign exchange earnings from fish and aquatic product exports, and (e) conserve the aquatic environment.

Institutional Setup for Managing the Crops, Livestock, and Fisheries Sectors and Implementing Climate Change Policies and Programs

The management of the crops, livestock, and fisheries sectors is carried out by completely different institutions and agencies in Sri Lanka at both national and provincial levels with many commonalities and complexities. The crop production subsector is divided into plantation crops, non-plantation food crops, and export crops. Accordingly, these sectors are coming under the purview of different ministries and line agencies and research centers/institutes. At the national level, the plantation crops sector is under the purview of the Ministry of Plantation Industries (MPI) with the Tea Research Institute (TRI). The Coconut Research Institute (CRI) and Rubber Research Institute (RRI) are mandated to carry out research, development, and extension work related to the respective disciplines. The non-plantation food crops sector is under the purview of the Ministry of Agriculture (MOA) with the Department of Agriculture (DOA) being the responsible entity, while the Ministry of Minor Export Crop Promotion (MMECP) looks after the interests of the export crops sector (except tea, rubber, and coconut) with the Department of Export Agricultural Crops mandated for research, development, and extension activities. The Ministry of Sugar Industry Development (MSID) with the line agency Sugarcane Research Institute (SRI) is responsible for research and development of the sugar sector in the country. The Department of Animal Production and Health (DAPH) and the Veterinary Research Institute (VRI) are mandated with research and development in the livestock subsector as well as with the conservation of indigenous livestock germplasm. The livestock sector is under the purview of the Ministry of Livestock and Rural Community Development (MLRCD). The Ministry of Fisheries and Aquatic Resources (MFAR) is primarily responsible for formulating policies, plans, and programs for the development of fisheries and aquatic resources with the Department of Fisheries (DOF) being the main responsible entity for program implementation.

The provincial-level activities concerning the three sectors are carried out by the relevant provincial ministries and provincial departments of respective sectors. For example, there are eight provincial ministries representing the crops, livestock, and fisheries sectors identified at different levels of importance according to the area of interest within the province. The Department of Agriculture, Department of Animal Production and Health, and Department of Fisheries and Aquatic Resources Development are devolved subjects by the constitution of Sri Lanka having their sister departments at the provincial levels.

Given the diverse and dispersed policy framework and the related institutional setup in place with regard to crops, livestock, and fisheries sectors, the governance and regulations of adapting to and mitigating climate change risks are even more dispersed. Though the coherence of policies could be seen in sectoral policies and a good integration of those in the environmental and climate change policy, the strategic priorities and action plans need a close attention as there is a certain level of non-coherence and non-integration when policies are translated to the work plans, the implementation of which is coming under the purview of different government institutions working independently.

UNFCCC Negotiation and Adaptation-Related Policies of Sri Lanka

Though Sri Lanka was a party for the UNFCCC and the Kyoto Protocol as discussed above, the internal development thrust was not focusing on climate change and its impacts until recent years. This was mainly due to the domestic security issues, which were also aggravated with the devastating Asian tsunami disaster in 2004 that affected Sri Lanka significantly. The national policy focus on climate change was boosted mainly with the intense negotiations on adaptation at the UNFCCC COP13 held in Bali, Indonesia. At the COP7 held in 2001 in Marrakesh, Morocco, the decision was taken to establish a work program to support the least developed countries (LDCs) to include the development of the National Adaptation Programme of Action (NAPA). The NAPA focuses on urgent and immediate needs for which further delay could increase vulnerability or lead to increased costs at a later stage. During the negotiations, it was implied that NAPA would be the base document for provision of immediate adaptation finances for vulnerable countries. Though this was a turning point in adaptation-related actions globally, not being an LDC, Sri Lanka was not included in the program. However, this decision created a momentum within Sri Lankan environment discourse evident with different dialogues and events on adaptation requirements.

The famous Bali Action Plan (BAP) that laid the road map for a global agreement in 2009 (at COP15) recognized the four main pillars of negotiations, viz., mitigation, adaptation, technology, and finance, and had a significant influence in local climate change policies, especially in relation to adaptation. Adaptation was brought up frequently in national policy discussions in post-BAP times. This is evident in the Action Plan for *Haritha Lanka* Programme in Sri Lanka, which included a dedicated mission on climate change with predominant focus on adaptation. In 2009, the Sri Lankan government forwarded an "information and views" submission to UNFCCC as agreed upon in COP 14. This submission proposed to promote "Sustainable Human Development Index (SHDI)" as the main global development index while recognizing ecosystem-based adaptation as the main strategy for adaptation. It also recognized the requirement of "hardware" (such as infrastructure) and "software" (socioeconomic processes) for adaptation. This vision laid the foundation to the development of the NCCP and NCCAS. The similarities between this submission and the NCCAS structure are high so that the national policy development on climate change could be attributed to global policy processes.

Mainstreaming climate change sensitivity into development process has been discussed widely in UNFCCC processes. This was highly emphasized in the Cancun Adaptation Framework agreed by the parties at COP 16 of the UNFCCC. The Sri Lankan government initiated a process of interministerial committees and discussions in 2010 along with the intersessions. The focus of NCCAS of Sri Lanka was placed at mainstreaming adaptation to economic development strategy of Sri Lanka, which shows how the international negotiation outcomes have put into action in national policy level. In addition, Sri Lankan cases have been submitted to UNFCCC in adaptation-related discussions (http://unfccc.int/files/kyoto_protocol/application/pdf/srilanka060209.pdf). For example, Sri Lanka forwarded a submission (http://unfccc.int/resource/docs/2013/sbsta/eng/misc02.pdf) on Nairobi Work Program (NWP) rollout to the Subsidiary Body for Scientific and Technological Advice (SBSTA) to the Bonn session in 2013 highlighting the adaptation requirements of its main economic crop, tea. This was the first time that Sri Lanka highlighted the adaptation requirements to stabilize its economy at SBSTA level and was a result of in-country discussions pertaining to climate policies. As per the Cancun Adaptation Framework (CAP Decision 1/CP17; http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=4) of 2010, all developing country parties were requested to develop and implement national adaptation plans (NAPs) building upon the experiences on developing NAPAs (Decision 1/CP.16, UNFCCC). As stated previously, Sri Lanka is currently in the process of developing the NAP bringing in an additional policy framework on climate change adaptation.

Conclusion

Sri Lanka, while being vulnerable to climate change in social, economic, and resource perspectives, has shown promise and strength to build up resilience with effective adaptive action to minimize the adverse effect of the inevitable changes of the climate. Despite the magnitude of the efforts and initiatives taken by the government, demonstrating its commitment and obligations to the global context by ratification of conventions, a serious gap still exists especially in the implementation of policies and strategies. Creating awareness among the general public for constructive actions to address complex climate change issues is still far below the expected levels. Increasing speculations make the much needed mainstreaming difficult to agree upon and implement, further exacerbating climate risks.

Sri Lanka pays more attention on adaptation to climate change, which is a reasonable decision as the country is not a main polluter in the global scenario. However, mitigation also needs to be considered when planning national development programs to support internationally accepted targets to reduce GHG emissions. In the context of managing expectations of the public and decision makers regarding the adaptation process, it is an urgent need to formulate a coherent work plan focusing on a commonly shared vision, involving all principal stakeholders, and reconciling diverse perspectives. One key recommendation is to carefully plan and execute long-term national programs for supporting public participation in climate change adaptation aimed at educating and building capacity of all stakeholders.

Sri Lanka owns a cohesive policy environment, which is conducive for implementation of appropriate climate change adaptation and risk reduction plans. Hence, it is a duty left with the policy implementers to identify the specific needs of the sectors and climate-proof the sectoral development initiatives of the country to ensure sustainability. Participation of all stakeholders, especially the general public, needs to be realized in every single step during this process by building capacity especially at the local level to help communities understand the climate risks and link them to sectoral activities. Thus, the programs should be designed and targeted accordingly to meet the expectations of a diverse group of stakeholders. Effective mainstreaming requires informed consensus on climate change risks, objectives, and policies that are based on a good understanding of the roles and responsibilities of all players, including ministries representing the crops, livestock, and fisheries sectors, other line ministries on environment and planning, and the participation of vulnerable communities. Shared responsibility is fundamental to successful implementation of targets having common goals.

As perceived especially in the Asia-Pacific region, responding or reacting to climate change has become the sole responsibility of environmental agencies. This situation is particularly challenging for a country like Sri Lanka where an accelerated growth rate in the economy is expected during the postwar period and due to the Herculean task of obtaining participation of people in the war-affected areas in the implementation of activities for a common goal. Given that the adaptation strategies are always entangled with livelihood activities, the responses to climate change will no doubt come under increased scrutiny and pressure. Hence, the mainstreaming of climate change adaptation actions needs to be matched by adequate capacity building and awareness attempts, tailor-made for the different role players.

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Energy Efficiency in Developing Economies: The Need for a Strategic Response to Climate Change in Sub-Saharan Africa (SSA)

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Abstract

This chapter investigated the role of energy efficiency as a means of meeting energy needs in the developing economies of West Africa (a region suffering from energy poverty), as well as adaptation to global warming, Climate change and its related risks. It draws on a literature survey to buttress the fact that energy efficiency remains the surest pathway to curb energy and resource wastage, and also reduction of the impending consequences of man-made carbon emissions to the ecosystem. The chapter compares energy profiles and climate vulnerabilities of three West African states. The metrics used in this study can be used for the easy assessment of climate risks posed by inefficient also energy usage, deforestation, and negative trends in the transportation sector of countries in the West African region.

Keywords

Energy efficiency • Climate Change • Strategic response • Risks • Sub-Saharan Africa • Technology and Innovation

Introduction

Climate change is among the major challenges the African continent faces today. In addition to handling matters related to climate impacts on agriculture as the project CALESA (http://www.calesa-project.net/) did, there is a pressing need to look at other mitigations options. In this context, there have been a number of persistent questions on uncertainties in the level of variability in the climate system and whether factors such as an increase in solar irradiance or a reduction in volcanic activity might account for a substantial amount of the warming seen in the twentieth century (Crowley 2000). A set of studies and detailed comparisons of climate models suggest that anthropogenic changes, particularly increases in greenhouse gases (GHG), are probably responsible for climate change (Crowley 2000).

The United Nations Framework Convention on Climate Change (UNFCCC) defined *climate change*s as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere, in addition to natural climate variability observed over comparable time periods (UNFCCC 1994). The convention also described the term "adverse effects of climate change" as changes in the physical environment or biota resulting from climate change, which has significant deleterious effects on the composition, resilience, or productivity of natural and managed ecosystems or on the operation of socioeconomic systems or on human health and welfare (UNFCCC 1994).

The energy sector remains one of the main contributors of greenhouse gas emissions (IEA & UNEP 2007). The current global energy situation is vulnerable and expensive, threatening the climate and eroding energy security, and the growing energy needs of the developing world pose a major challenge for energy decision makers (OECD 2007). The current situation of access to modern energy services in Africa is alarming. It is worse in the rural areas of many sub-Saharan

African (SSA) countries with the exception of South Africa, where they heavily depend on biomass (wood, animal dung, agriculture waste, etc.) for more than 80 % of their cooking energy use (ECA 2007). Electricity use per capita is less than 2 %, and in most African countries electricity consumption has stagnated due to low supply and an inadequate form of energy supply for the end usage (ECA 2007). It is salient to note that the level of energy utilization in an economy, coupled with the efficiency of conversion of energy resources to useful energy, is directly indicative of the level of development of the economy (ECN 2003). It is then obvious that the lack of access to sufficient, quality, and reliable energy critically constrains socio-economic advances and development. This brings to light the unique challenge that Africa and other developing economies face today in reaching their development goals in a sustainable manner. Population growth in these areas of the world increases the number of people without access to modern energy services; this increases, indirectly, the proportion of people using animal dung, fuel wood, and kerosene as cooking fuels which will, in turn, increase carbon emissions.

The rapid and intensive economic and industrial growth in developing countries (especially the fast-growing economies such as China and India) is causing higher energy demand. The rising oil and gas demand, if unchecked, will accentuate consuming countries' vulnerability to supply disruptions and price shocks, causing poorer countries to be at risk of loss of real income and with adverse impacts on the budget deficits and account balances of importing countries (IEA and UNEP 2007). Adverse impacts caused by climate change will be most striking in the developing nations because of their geographical and climate conditions, their high dependence on natural resources, and their limited capacity to adapt to a changing climate (UNFCCC 2007). It is also salient to state here that relative to people living in developed countries, developing economies are more vulnerable to Climate change due to inadequate resources (financial, technologies, human and social capital) to adapt and mitigate the risks of climatic changes (Commonwealth 2008; World Bank 2011). The developing countries in regions of Africa, Asia, Latin America, and Small Island Developing States (UNFCCC 2007; Commonwealth 2008) will be adversely affected. Billions of people living in developing countries face the challenges of food and water shortages and greater risks to their health and life as a result of climate change (UNFCCC 2007). The effects of droughts with reduced agricultural yields are seen in famished areas of Somalia and increased flooding from sea surges or rivers in cities such as Kolkata and Mumbai, India; Dhaka, Khulna, and Chittagong; and large areas of Bangladesh (UNFCCC 2007; Commonwealth 2008).

The energy sector has been identified as the main problem area, but it may also be part of the solution. Energy efficiency will be the fastest way to meet global energy needs (OECD 2007) and will decrease the impact of the energy sector on the climate and the consequent danger posed by Climate change to entire humanity.

The objective of this chapter is to buttress the fact that promoting and implementing energy efficiency are among the most promising approaches to meeting the world's energy needs, especially in the developing economies of West Africa. Secondly, this chapter illustrates the fact that energy efficiency offers a useful contribution to curbing global warming and helps to address the challenges posed by climate change.

This chapter draws on a literature survey as evidence of the fact that energy efficiency remains the surest pathway to curbing energy and resource wastages and averting the impending and dire consequences of mankind's carbon emissions that are distorting the ecosystem. The chapter compares energy profiles and climatic vulnerabilities of three West African states and then continues by proposing strategies that can be used to tackle Climate change in West Africa through efficient energy use.

Energy Usage in West Africa

The West African states comprise fifteen countries with a population of about 262 million, representing 40 % of the total population of SSA (Ouedraogo 2011). In 1975, the member states of West Africa formed the regional body called Economic Community of West African States (ECOWAS). ECOWAS is typical of SSA countries, which is known for having the lowest per capita energy consumption rates compared to other developing economies in Latin America, Europe, Asia, and Middle East (UN-EDESA 2004). It would seem controversial to talk about energy efficiency in SSA when one only looks at the low-energy consumption per capita statistics. The ECOWAS region is rich in commercial energy resources in the form of petroleum, natural gas, and also hydro resources that could be used to generate electric power. However, most of the rural population lacks access to modern energy that forces them to resort to crude energy sources without considering the environmental consequences.

The combined gross domestic product (GDP) for ECOWAS was estimated at \$139 billion as of 2005, and Nigeria's economy is larger than the combined GDP of all other ECOWAS countries, with a GDP of \$78 billion. According to the US Energy Information Administration (EIA) (2011), Nigeria has 37.2 billion barrels and 187 trillion cubic feet of proven oil reserves and natural gas, respectively, with a production capacity that has been close to 2.9 million barrels per day but is, however, producing less than that due to vandalism and sabotage. As of 2003, Nigeria had 96.3 % (5.6 quadrillion Btu) of ECOWAS energy production, consumed 66.7 %, and emitted 76.9 % (33.16 million metric tons) of the community's carbon emissions (Clough 2007). So when one is analyzing the political, socioeconomic, and other related issues about ECOWAS, it is not out of place to see Nigeria taking a center stage.

Table 1 below shows energy usage, electric power consumption, and carbon emissions in three ECOWAS states.

Household Energy Consumption in West Africa

A survey of energy efficiency practices in Nigerian households by Abdul Majid and Hussaini (2011) showed that most people do not fully understand the energy efficiency concept apart from the fact they have to use energy-saving bulbs for

Table 1 Energy usage and vulnerabilities of three ECOWAS states

Mali	80 % of the population is employed in agriculture
	44 % of the country's GDP comes from agriculture, animal husbandry, and fishing
	Over 90 % of energy consumed comes from biomass
	Substantial rise in the informal wood fuel supply sector is accelerating the deterioration of the ecosystem
	Anticipated construction of 20 dams along Niger River, a resource shared between four countries
	Proposed dam impact assessments do not look at the effects of climate change on anticipated water flows
	No coordinated emergency/disaster management system exists
	Lack of information regarding risks and associated economic impacts
Nigeria	Agriculture is rain-fed; only 1 % of the 33 % of arable land is under irrigation
	70 % of the population is employed in agriculture
	30.1 % of energy consumed is from biomass while 43.3 % is from petroleum products
	80 % of the population use biomass for their energy needs
	Modern renewable energy production represents less than 5 % of the country's energy consumption
	Volatility in the Niger Delta generates instability in upstream petroleum supply industry
	50 % of oil production is offshore
	Oil production and gas flaring has damaged surrounding marine ecology and agricultural lands irreversibly
	Country's financing hub – Victoria Island – is vulnerable to impacts of the rise in the sea level
	Lake Chad – an important freshwater source for the four countries that surround it – is only 5 % of its original size
Senegal	Agriculture is rain-fed
	Substantial volumetric reduction from 650 m^3 to250m^3 in the Senegal River, the country's main hydroelectric source 43.5 % of all energy consumed comes from biomass
	90 % of all electricity produced comes from hydrocarbons
	One fifth of electricity generated is wasted due to technical inefficiencies
	Petroleum imports account for more than 43 % of revenue exports, making the country vulnerable to fluctuating oil prices
	Rising sea level is causing the salinization of freshwater table
	1,350 km coastline with flat interior terrain
	Over 75 % of the population lives less than 60 km from the coastline

Source: Helio International (2007) www.helio-international.org

lighting and switch off appliances when leaving their houses. The survey was carried out in urban and semi-urban areas of the country. Most rural households in SSA rely primarily on traditional biomass energy supply for their cooking fuels, such as firewood, charcoal, and agricultural waste (UN-EDESA 2004). Studies show that the scarcity and higher cost of these biomasses resulted in switches to lower-quality biomass fuels such as cow dung and agricultural residues (Kaale 2002 as cited in UN-EDESA 2004); this was established in Ethiopia in one of these

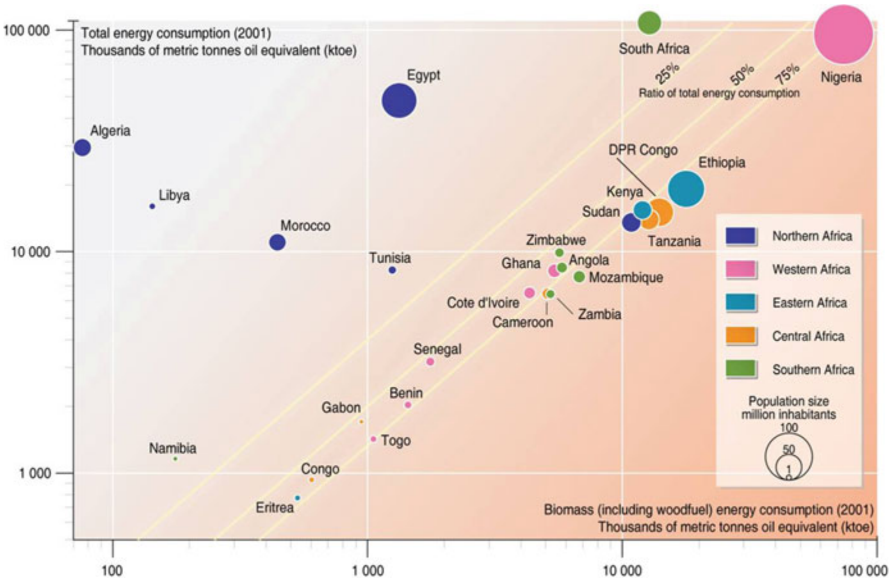

Fig. 1 Biomass fuel usage in Africa

studies but is typical of most SSA countries. The use of biomass fuels causes myriads of problems to humans and the environment. The harvest of wood for fuel leads to deforestation, erosion effects, and ecological degradation, and the incomplete combustion also leads to indoor air pollution. Figure 1 shows that the wood fuel usage in African and West African countries is among the highest in the world.

Most households in the urban areas in sub-Saharan Africa use a mixture of fuels, which may be due to higher income and having better access to modern energy services. Electricity (primarily from coal-based power stations) dominates household energy consumption in South Africa; others use relatively cleaner energy forms such as electricity, LPG, and kerosene.

Another survey carried out in Nigerian cities showed that incandescent bulbs (40–200 W) are principally used for lighting, and this serves as a significant source of energy wastage (CREDC 2009). Most homes, commercial buildings, and government buildings still have such bulbs installed. Kerosene lamps and candles are common lighting used in most rural areas in SSA. Another study found out that kerosene is the main energy source for lighting in the rural areas of the East African country (Ethiopia), while in urban areas electricity was the main source (UN-DESA 2004). However, Mekonnen and Köhlin (2009) noted that households in Ethiopia engage in multiple fuel use (fuel stacking) rather than the idea of a complete switch to other (more expensive) fuels as their incomes rise. Fuel stacking (multiple fuel use) in urban areas in sub-Saharan Africa (with no exceptions in West African states) remains a challenge for the campaign for energy efficiency. The case of a complete fuel switch has been recorded in Senegal where deliberate government policy, giving tax breaks (exemption from customs duties on equipment connected to butane), and later awarding subsidies for this fuel in 1987 caused the amount of LPG being used to increase from less than 3,000 t in 1974 to nearly 100,000 t in 2000. The report as cited in UN-EDESA (2004) stated the constraints and challenges of achieving complete success in the fuel diversification process in Senegal.

This study did not consider the energy consumption of residential buildings for most of the populace in ECOWAS states due to a lack of sufficient data. Moreover, most of the ECOWAS states do not need much energy to warm their buildings because of their location in the tropics; rather, there is a need for air conditioners for hot climates. However, energy-inefficient air conditioners remain a matter for the high-income earners among the urban populace in the region.

Agricultural Energy Consumption

The dearth of data on energy use in the agricultural sector in West Africa remains an issue. This is not unique to the region but seems to be a general problem for Africa with the exception of a few countries. Most economies in Africa depend on agriculture, except for countries that are largely dependent on mining and oil exports such as Botswana, Cameroon, Congo, Nigeria, South Africa, Zambia, and Zimbabwe (FAO 2012). The lack of mechanized agriculture in Africa forces those involved to use human labor (readily available from the teeming human population), serving as an important source of power for agriculture in West Africa and other SSA countries (UN-EDESA 2004). Across West Africa, energy use in agriculture is very low. However, energy use is still involved in agricultural production and processing. The use of fossils in drying agricultural products remains a practice.

A significant proportion of energy used in the transport sector is linked to the distribution and marketing of agricultural products (FAO 2012). According to FAO (2012), it is not easy to separate the biomass used in agriculture from that used in households except in economies with large commercial farming subsectors such as Côte d'Ivoire, Kenya, South Africa, and Zimbabwe.

The Transportation Sector

The United Nations Economic Commission for Africa (UNECA) (2011) states that the industrial and transport sectors are the biggest consumers of fossil fuels in Africa. The transport sector accounts for over 60 % of the crude oil consumption in the region. Sokona (2012) also stated that the transport sector consumes a large proportion of the commercial energy supply and passenger transport by car absorbs the vast majority of the energy used in the transport sector. This is obvious in some West African states where a poor network of road infrastructure and mass transit programs make cars the most predominant form of transport in most African countries. According to Trans-Africa Consortium (2010), the road network suffers from a

Fig. 2 Traffic congestion on a major road in Abuja, Nigeria (Source: nigerianewsline.com)

lack of regular planned expansion and from a lack of long-term maintenance. This affects energy supplies and increased carbon emissions from the engines of numerous passenger cars used for transportation. The transport sectors in Nigeria, for instance, is in a poor condition considering the number of trucks distributing refined petroleum, food crops, other goods, and raw materials from one region to the other. Most of these trucks and cars are imported as secondhand products and emit more carbon emissions as they are near the end of their life cycle. The poor network of roads leads to traffic jams in most urban cities with cars emitting more carbon emissions than they would necessarily do when traveling the same distance.

It is pathetic to behold the traffic jams in most cities in some developing nations with the consequent carbon (CO_2) emissions and working hours wasted on those roads. Figure 2 gives an idea of the amount of energy wasted in traffic jams in major cities in some developing countries. The cars use more energy to get to a particular location due to "Go Slow," a term for a peculiar traffic jam in Nigeria, where cars are forced to move at a snail's pace on the roads to avoid potholes. The Trans-Africa Consortium (2011) cited the case of the Bus Rapid Transit (BRT) in the commercial capital of Nigeria, Lagos. BRT recorded a reduction of 32 % fuel consumption for vehicles used along its dedicated corridors, resulting in the reduction of 25,000 t of CO_2 per year due to the implementation of the BRT services (20 times less CO_2 emitted per passenger transported compared to private car). The BRT case is different when compared to other West African cities such as Dakar and Ibadan in Senegal and Nigeria, respectively, where old minibuses are used to transport passengers. Another study cited by the Trans-Africa Consortium in Ghana stated that fuel consumption for minibuses and taxis is much higher per passenger/km than for larger city buses. *The results of the study suggest that it would require 22.5 times more fuel for a taxi to* *carry the same number of passengers than for a large bus over the same distance, and 6.6 times more for a minibus. In 2008, 107 MMT buses used 1.3 million litres of diesel to carry about 12.5 million people. Therefore, 400 minibuses or 900 taxis would be required to carry the same number of people over the same distance, and they would use about 8.5 million and 28.8 million litres of diesel respectively, more than doubling the fuel required* (Trans-Africa Consortium 2010). The overcrowding of the larger buses also helped to increase the index results for the buses.

Industrial Energy Usage

West Africa is not yet industrialized but the mining and raw materials extraction industries dominate the industrial sectors. There are, however, a few energy-intensive industries, such as VALCO, a transnational aluminum production company in Ghana, petroleum refining companies in many countries, and fertilizer companies and steel and cement plants in Nigeria (Sokona 2012). The cement industry is one of the most energy-intensive sectors. According to the World Bank (2009), energy represents about 20–40 % of total production costs and also a significant source of greenhouse gases, accounting for about 5 % of the annual global anthropogenic carbon dioxide emissions – representing 1,800 million tonnes of CO_2 emissions in 2005 from the use of fossil fuels and chemical reactions during clinker processing. The average CO_2 intensity ranges from 0.65 to 0.92 tCO_2 per tonne of cement across countries with a weighted average 0.83 tCO_2/t1.

The World Bank (2009) also reported that the cement industries recorded 203 out of 4,364 CDM projects submitted for registration to UNFCCC as of January 1, 2009. Africa registered only 28 CDM projects (2.1 %) out of 1,300 projects registered worldwide, with only three new projects submitted for registration from the cement industry in Africa. The three projects registered were the bundled blended cement projects in two plants owned by WAPCO in Nigeria, the Jatropha plantation and biomass residues for partial substitution of coal in the SOCOCIM plant in Senegal, and biomass and biomass residues used as alternative fuels in a CEMEX plant in Egypt.

The registered CDM projects involved the most commonly used methods of cement blending, fossil fuel substitution and switching with alternative fuels/biomass, waste heat recovery processes, and other energy efficiency measures. The knowledge that would have been developed from engaging in the CDM projects would have also been transferred to other sectors of the economy. However, the whole of SSA countries and not just ECOWAS ignored this great opportunity, allowing China and India to register 110 and 49 projects, respectively.

It is not uncommon to see this kind of response in Africa where some countries such as South Africa, Cote d'Ivoire, and Kenya, which do not currently produce oil, have more efficient refineries than oil-producing countries such as Nigeria, Angola, and Gabon. As a result, these countries with more efficient refineries have become regional suppliers of oil products. The energy usage pattern of an average end user in Nigeria, for example, is typical of a government that has not made a serious effort to stop the flaring of associated gas in oil refining in more than 50 years of crude oil exploration.

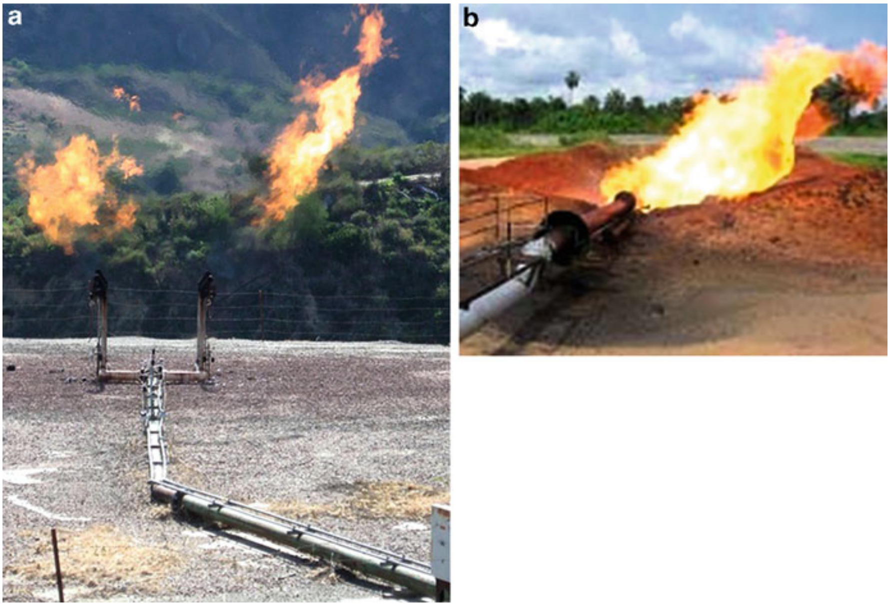

Fig. 3 (**a**) Gas flaring in Nigeria (Source: www.justmeans.com), (**b**) Gas flaring in Nigeria (Source: Friends of the Earth International)

The pictures in Fig. 3a, b depict what is seen in the Niger Delta region in Nigeria where corporate entities without any serious government intervention have wasted enormous gas resources and money that should have accrued from natural gas sales for over 50 years. Beyond that, they have contributed to global warming with all impunity. One has to wonder why these corporate entities – most of them unfortunately multinational – do no tact on the findings of their sustainability reports around the globe.

Nigeria remains a good example of where energy efficiency must be taken more seriously because of its leading role in ECOWAS and Africa, and there cannot be sustainable development in ECOWAS if countries such as Nigeria are not actively helping. The best place to start promoting the concept of energy efficiency and reducing carbon emissions may be with the governments in the main developing economies of ECOWAS. These countries must learn to show leadership and direction.

Energy Consumption and Climate Change

The climate is changing drastically and is a matter of concern to all well-meaning people in the world. The diagram in Fig. 4 shows the change in global temperature, carbon dioxide, and dust concentrations over thousands of years. These are dangerous trends which humanity must consider and make efforts to avert the impending and dire consequences. The satellite images of Lake Chad over a 30-year period (Fig. 5) portray a very dangerous trend for the environment and the ecosystem, which seriously threatens the livelihood of the human population in the neighborhood.

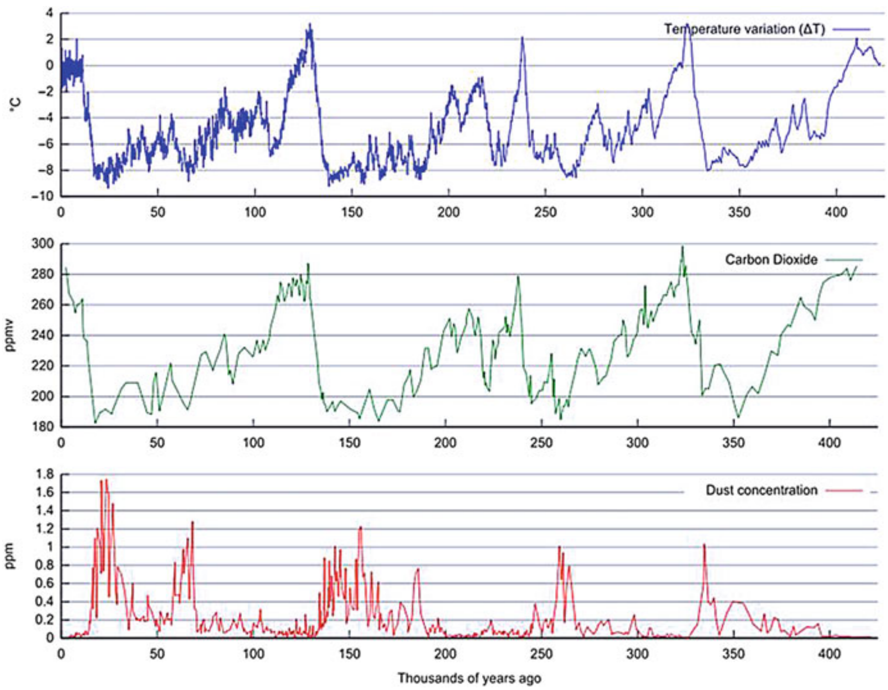

Fig. 4 Change in temperature, CO_2, and dust concentration (Source: http://en.wikipedia.org/wiki/Climate_change)

Both the low-income countries and the developed countries all contribute to Climate changes. Lack of access to modern energy services constrains people living in poor countries to resort to low-quality energy sources with high carbon emissions. Poor countries also lack the infrastructure (national grid, off-grid generation, greenhousing estates, regulatory bodies, energy standards, etc.) that ensures energy efficiency. In cases of developed countries with high energy- intensive sectors, the location of high energy-intensive industries and power generation from fossil fuels all contribute to high carbon emissions and consequently to climate change. It is not surprising to see that the developed countries with high energy intensity have greater carbon emissions than the developing countries.

Comparison of Energy Profile and Risks of Climate Change in Three Selected West African States

This study selected Mali, Nigeria, and Senegal for a comparison based on their energy profiles and risks of Climate change. Table 1 gives a summary of the economic profile, energy usage, and Climate change vulnerabilities of these three states. Table 2 states the energy use (kg of oil equivalent per capita) indicator, electricity consumption (kWh per capita) of the three countries and other ECOWAS

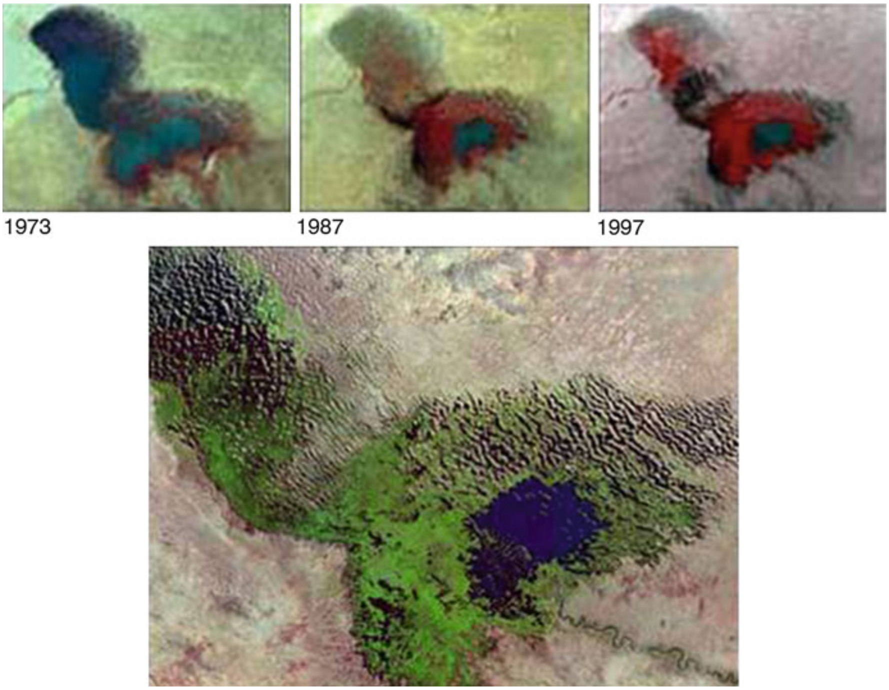

Fig 5 Satellite picture of Chad Lake in 2001 (Source: en.wikipedia.org/wiki/Lake_Chad)

countries in 2009, and then the consequent increase in the level of carbon emissions and degradation of forest reserves.

Mali has 80 % of its population employed in agriculture with 44 % of the GDP coming from the agricultural sector. Nigeria's population also has 70 % of the population employed in the agricultural sector. Biomass constitutes over 90 % of all energy consumed in Mali, a reasonable number of Nigerians use biomass, while Senegal seems to have a much lower consumption of biomass. Senegal forced a certain proportion of its population to switch to LPG from biomass and has a lower percent of biomass consumed compared to Nigeria and Senegal.

Nigeria produces the largest quantity of crude oil in West Africa and also consumes more petroleum products than the other two countries. Senegal generates electricity mostly from hydrocarbon sources compared to Nigeria and also Mali, which has an energy supply mix of natural gas and hydro resources. Based on the data in Table 2, Nigeria uses more energy than Senegal but the latter generated more electricity than Nigeria. Mali has no data on its energy use and electricity generated in the World Bank (2011) report. Moreover, Nigeria has emitted more carbon than Senegal. This is obvious due to the gas flaring activities of the crude oil exploration in Nigeria. Nigeria has lost more forest reserves (sq. km) than the two other countries from 2000 to 2010, followed by Mali. Senegal seems to have had better control of her wood fuel consumption and preservation of her forest resource.

Table 2 Energy use and carbon emission and forest reserves in ECOWAS from 2000 to 2010

Country	Year	Energy use (kg of oil equivalent per capita)	Electric power consumption (kWh per capita)	CO_2 emissions (metric tons per capita)	Forest reserves (sq. km) ('000)
Ghana	2000	404	330	0.3	60.9
	2005	394	247	0.3	55.2
	2008	407	267	0.4	–
	2009	388	265	–	–
	2010			–	49.4
Côte d'Ivoire	2000	406	173	0.4	103.3
	2005	535	175	0.4	104.1
	2008	541	202	0.4	–
	2009	535	203	–	–
	2010		–	–	104.0
Mali	2000	–	–	–	132.8
	2005	–	–	–	128.9
	2008	–	–	–	–
	2009	–	–	–	–
	2010	–	–	–	124.9
Senegal	2000	252	106	0.4	89.0
	2005	257	163	0.5	86.7
	2008	243	164	0.4	–
	2009	243.	196	–	–
	2010	–	–	–	84.7
Nigeria	2000	726	74	0.6	131.4
	2005	745	128	0.7	110.9
	2008	736	127	0.6	–
	2009	701	121	–	90.4
	2010	–	–		–

Source: http://ddp-ext.worldbank.org/ext/ddpreports/ViewSharedReport

However, Senegal is still vulnerable to flooding since it has a 1350 km coastline with flat interior terrain and housing, and over 75 % of its population lives less than 60 km from the coastline. Nigeria also has 850 km of low-lying coastline, but Mali's proximity to the north of Africa makes it vulnerable to desertification and other associated climatic risks. The drying up of Lake Chad and the loss of forest reserves are indications of climate change in West Africa. This is shown on Fig. 5, a satellite image of Lake Chad in 2001. The countries near to the north of the Sahara face more desertification, low rainfalls, low agricultural outputs, and migration, while low-lying coastline countries may soon face salinity of fresh water and flooding of low-lying plains. The comparison shows that all three countries face peculiar climatic risks but their energy efficiencies differ. Senegal is more energy efficient than Nigeria and Mali.

Conceptual Approach

Energy efficiency is simply the ratio of energy services output to energy input (Herring 2006). The concept of energy efficiency has to do with getting the most out of every unit of energy produced or consumed. This concept is deeply rooted in eco-efficiency which emphasizes the use of fewer resources to produce more things. Eco-efficiency does not merely focus on material use and waste reduction but is also concerned with resource productivity by maximizing the value added per unit of resource input. Eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring about a better quality of life while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the Earth's estimated carrying capacity (Michaelis 2003).

Energy efficiency can be seen as the Cinderella of the global campaign against climate change (KPMG 2010). It seems to lack the glamour of clean and renewable energy technologies and has historically attracted less generous tax benefits and other incentives, but the climate does not care whether CO_2 is reduced by greener and cleaner technology or lower energy consumption, as long as it is reduced (KPMG 2010). After several literature reviews, it is obvious that the concept of energy efficiency remains the short-term and sustainable approach to energy poverty in developing countries. Africa and other developing nations can adapt better to Climate change by adopting energy efficiency as this will serve both as a short- and long-term measure. Case studies cited in literature portray the fact that energy efficiency is yielding the expected results (USAID 2009), and these case studies are cited in this chapter.

Energy efficiency is widely accepted as the most cost-effective way to mitigate climate change and accounts for 50 % of the potential halving of energy-related CO_2 emissions by 2050 (WBCSD 2010). Stabilizing the concentrations of these gases at a level that would avoid human distortion of Earth's climate requires drastic changes in the fuel mix, more efficient production and use of energy, and measures that prevent carbon dioxide from being released to the atmosphere over geological timescales (IEA and UNEP 2007).

Energy Efficiency Is Key to Energy Security

About 1.6 billion people in developing countries, making up one-quarter of the world's population, do not have access to electricity in their homes, while some 2.5 billion people rely on traditional fuels and technologies for cooking and heating (IEA and UNEP 2007). This threatens the realization of the United Nations Millennium Development Goals since the identification and implementation of cost-effective policies to meet these needs are both difficult tasks as they often encounter resistance from industry and consumer interests (IEA and UNEP 2007). Energy security is increasingly seen as a prerequisite for sustainable development and poverty alleviation and a condition for achieving the UN's millennium development goals, including the aim to halve the proportion of people in poverty by 2015 (OECD and IEA 2010). The costs of inactivity outweigh those of implementing the required policies, so there is a need to develop effective policies, since providing access to sustainable clean energy supply is vital not only for curbing global warming but also for reducing poverty and misery in West Africa and around the world.

However, world energy consumption is predicted to increase by 54 % from 2001 to 2025, and much of the growth in worldwide energy use is expected to be in the developing world (IEO 2004). Since the first oil crisis of the 1970s, economic growth and energy consumption have stopped moving in tandem in many industrialized nations, but the world's energy needs have still grown steadily and will continue to grow, especially in the large emerging economies such as China and India. Energy efficiency will ensure that these developing countries do not toe the previous path of the developed ones. Collectively, the world can achieve some level of energy security if the developing economies use energy efficiently in their quest to industrialize.

Energy Efficiency as a National Strategic Response

In every risk lies an opportunity which can be explored. The Climate change is creating a business paradigm shift (Energetics 2009). Regional bodies, countries, organizations, and firms now have the responsibility to ensure that risks and opportunities are identified, assessed, managed, optimized, and effectively managed. The greatest risks and opportunities are likely to be driven by shifts in government policy, investment in technology and innovation, and the impacts of social change (Energetics 2009). The reality is that energy efficiency involves people, systems, software, technology, and organizations, all of which are linked together in new ways.

This chapter will closely look at four strategic approaches that could be used to enhance energy efficiency and curb Climate changes in West Africa. They are government policy and regulation, investment in technology and innovation, socio-cultural change, and then regional integration and cooperation towards energy efficiency and Climate change adaptability.

Government Policy and Regulation

The innovation required for developing energy-efficient technologies and social cultural change, to ensure efficient energy utilization by citizenry, is unlikely to take place without government direction (Praetorius et al. 2009). Some economists have emphasized that taxation could be used to spur innovation technologies as well as abate carbon emissions (Herring 2006). The direct taxation on the quantity of CO_2emissions will be an incentive across all fields of innovation that will help to save energy and/or reduce CO_2 emissions (Praetorius et al. 2009). This school of thought believes that taxation ushers in induced innovation because appropriate tax regimes on fossil fuel usage make its use more expensive for private and industrial consumer, making demand increase for energy-efficient technologies. This will motivate enterprise in the direction of a technology push for energy-efficient technologies (Praetorius et al. 2009). However, taxation as an instrument will only work in economies where people pay taxes and governments utilize taxes entrusted in its hands. This chapter does not hold the view that taxation alone as an economic instrument will be used to cut CO_2 emissions. Those economists that hold contrary views about the concept of energy efficiency should think of a systemic approach to tackling global issues and challenges. It is preferable to use an integrated approach that will involve the use of sustainable policies and scientific, technological, and sociocultural approaches to tackle the issue of climate change. Since the energy sector has been identified as the main contributor of emissions of greenhouse gases (IEA and UNEP 2007), policies that promote the more efficient production and utilization of energy contributing to a reduction of almost 80 % of CO_2 emissions (OECD 2007) should be introduced. Sustainable energy policy in developing countries will have to integrate energy efficiency as a measure to mitigate risks of climate change. Such energy policies will support the establishment of smart and off-grid power generation to avoid energy losses during long transmissions. Sustainable energy policy will support the increase in the energy supply mix of the country, with more emphasis on renewable energy sources than fossil energy sources. Government policies that support oil subsides do not encourage energy productivity, as seen in most oil-producing countries (McKinsey & Company 2007). The oil subsidies are responsible for the lack of energy productivity in the Arab Gulf which stand in contrast to what is obtainable in European countries and Japan (McKinsey & Company 2007; Licklider 1988). Oil and fuel subsidies seem to encourage energy wastage. Deregulation of the energy sector will go a long way in ensuring energy efficiency. Governments must stipulate standards for the major players in energy generation and distribution to ensure efficiency in the energy sector. Governments in developing countries can introduce policies that support energy efficiency, starting with programs aimed at the design and construction of green housing and buildings (with the retrofitting of efficient heating, ventilation, and cooling systems, lighting systems, and solar hot water heaters) for public utilities and commercial and private purposes. There are energy standards, green codes, and labels for products in the market, and it is strongly advised that ECOWAS countries ensure compliance in the importation of green products as this will ensure that energy-consuming appliances and equipment are used in the country. This also applies to legislation that will enforce efficiency in both the production and usage of energy. It is obvious that there will be future legislation for energy efficiency both in developed and developing economies if the issues of global warming and climate change are to be taken seriously. It has been the practice in a number of countries for governments to offer financial incentives for energy efficiency improvement schemes, based on government policy in this regard (UNE/A 2007). Incentives and tax rebates will foster a wider cooperation for efficiency among consumers and actors/players in smart grid networks and other energy enterprises. In developed economies such as in the United States, there are three main incentives which include production tax credits, investment tax credits, and grants for investors in energy efficiency (KPMG 2010); ECOWAS countries can copy this example.

Investment in Technology and Innovation

The challenges of Climate change can be tackled with technological innovations that will enhance energy-efficient technologies (OECD 2007), if not now, then certainly in the long run. There is a need for new institutions, management techniques, and market contracting arrangements that can serve as incentives which will, in turn, serve as the motivations for energy and materials users to seek out evermore efficient technologies that are ecologically friendly (Scarlett 2010). In Nigeria, for instance, there is a common assumption that Nigeria generates more than enough energy for their consumption and that the problem lies with management, distribution, and efficient utilization of the energy generated. Entrepreneurs are needed to exploit the opportunities created by energy wastage whereby there will be a shift in focus from compliance and risk management to market leadership in technological innovations that will drive the low carbon economy in developing countries like those of the ECOWAS states. Technological innovations are essential and required to reduce the amount of energy use and carbon (IV) oxide (CO_2) emissions, to monitor energy use (smart metering), and also smart switches for turning off and on during energy peak and off-peak periods. The use of incandescent bulbs (40–200 W) is a significant source of energy wastage and they are still commonly used (CREDC 2009). Most homes, commercial buildings, and government buildings still have such bulbs installed. Low-energy lighting technologies will serve as better alternatives for street lighting where incandescent bulbs are still in use in cities across most ECOWAS states. A case study on public private partnerships (PPP) initiated by Asian Electronics Limited (AEL) and nine cities using energy service company (ESCO) contracts described how the partnership worked alongside municipal corporations in India to install energy-efficient streetlights and upgrade central monitoring systems (USAID 2009). Lighting technologies are the quickest to retrofit, visible, and easily verifiable in energy-efficient projects, and its energy-saving potentials are instantaneous (USAID 2009). This would be a good starting point for energy entrepreneurs in Africa, like in Asia where some projects had started, such as those in India. The AEL's street lighting projects installed more than 25,000 waterproof energy-efficient tube lights and 100,000 retrofit energy-efficient tube lights, which are controlled by 4,000 automatic load monitoring systems at all of its switching points (USAID 2009). AEL projects were expected to realize energy savings of nearly 13 MW and carbon savings of approximately 40,000 t of CO_2 equivalent per year, thus achieving energy consumption savings of up to 60 % (USAID 2009). Technological innovations that offer energy savings are more helpful in solving energy inefficiency challenges in developing countries considering the size of the human population involved. Technological innovations for monitoring energy usage are already in the market to enhance energy efficiency. Public enterprises, business firms with numerous infrastructural bases, large industrial estates, and housing estate schemes in developing countries can monitor energy usage. It is important to note that most multinational corporations are making their operations more sustainable by investing in software that can help them manage their energy usage in response to large increases in utility costs (Worthington 2010). Software, such as ENXS produced by ENXSUITE, has been developed as a project portfolio management tool for the energy space. ENXS 6.0 works with utility billing systems, providing invoicing and reconciliation, and has introduced a new web services interface for smart grid and energy management integration (Worthington 2010). These developments may not take place in developing countries in the immediate future, but a good starting point will be through the deployment of smart meters and development of smart grids. Smart metering is a system used to measure the energy consumption rate of households and communicate the information to both the user and the local utility provider for monitoring and billing purposes (Bleischwitz et al. 2009). The smart metering system can be coupled with energy efficiency services (energy audit and energy performance contracting, etc.), home technologies, and new smart grid two-way control systems to integrate distributed generators. Smart metering provides the possibility for residential customers to obtain more accurate bills and prepayment options, therefore initiating the consciousness and behavioral change required to monitor their energy use, making it easier for them to switch to better energy suppliers (Bleischwitz et al. 2009). It has been recently observed in Nigeria that most electricity end users who use smart meters turn off their appliances and switch the meters off while they are away to avoid their meters from recording energy use. They now avoid the cost of leaving their appliances on when not in use. The development or transfer of these technological innovations will enhance energy efficiency in developing countries. It will assist homes and business firms to monitor energy consumption and avoid wastage. The innovations seen in the monitoring and managing of energy portfolios has created opportunities for energy entrepreneurship where jobs can be created for managing energy portfolios in developing economies especially for firms that generate their own energy.

The mobile telecommunications industry stands out as a good example of business that needs energy generation for its operation, and they have acquired numerous power generation bases. Optimizing energy efficiency in this sector will not only reduce its environmental impact but also cut operating costs and help to make communication more affordable for everyone. Finding new efficient energy solutions also helps spread access to communications by opening up more options for the installation of radio sites in a sustainable manner with low impact (Ericson 2007).

Sociocultural Change

The cultural capital of somewhere can be described as a cultural background and a basic value system that is shared by the individuals in a community and manifests in their attitudes and habits, including consumption patterns (Bruno et al. 2008).

The consumption pattern and customer responsiveness to new energy-efficient technologies (OECD 2007; Bruno et al. 2008) affect the energy consumption and CO_2 emission of that particular location. The sociocultural approach to energy efficiency is to increase the energy utilization by sharing with others or selling access to them (Bleischwitz et al. 2009) from the excess capacity one has generated for his/her own consumption.

Most developed economies are seriously developing green and sustainable communities who share resources, as seen in smart grid energy generation. There are community energy generation enterprises in several countries which include car- and bike-sharing enterprises. Car-sharing is the concept of renting a car every time one is needed instead of purchasing one outright (Bleischwitz et al. 2009). Car-sharing reduces the number of vehicles on the road. Thus, reducing the energy input and the raw material charge of car manufacturing significantly decreases the CO_2 emissions from the usage of the car (Bleischwitz et al. 2009). Effective transport systems with good mass transit buses and railway systems could be an alternative for developing countries that do not have entrepreneurs who can venture into the car-sharing business. It remains important that ECOWAS and other developing countries should educate their citizens on the need to avoid following the unsustainable path of the Western world with wasteful lifestyles and high energy usage. Developing countries must engage in enlightening their citizens of a social transformation that will embrace efficient resource use and energy efficiency. A case study on the use of incandescent bulbs with energy consumption of 40–200 W as mentioned above suggests a lifestyle of energy wastage across Nigeria (CREDC 2009). It is also evident that most of these incandescent bulbs are left switched on to know when public electricity supply is available. It is salient to say at this point that to introduce a sociocultural change, governments in developing countries must show direction and leadership by displaying efficiency in all resource usage, minimizing energy waste in the generation and distribution of energy, installing energy-efficient technologies in government building, and engaging in other green programs.

Regional Integration and Cooperation Towards Energy Efficiency and Climate Change Adaptability

ECOWAS as a regional body will play a strategic role in the promotion of government policies and regulations on energy standards and its response to climatic challenges. It has to strengthen the already existing institutions such as the ECOWAS Centre for Renewable Energy and Energy Efficiency, which has the mandate to help develop renewable energy and energy efficiency markets in West Africa, formulate policy, and build capacity and quality assurance mechanisms, as well as well-designed financing plans. The center is also supposed to implement demonstration projects with the potential for future regional expansion.

Energy efficiency can be shaped by a social network where the actors in the network learn by sharing knowledge, ideas, and best practices. The industrial, transport, agricultural, energy sectors could have existing tacit knowledge, perceived truths, routines, practices, and methods regarding energy efficiency within these sectors. These established energy efficiency measures in one sector can be transferred to a different sector through regional communities of practice and trade associations which guide and regulate practices in these sectors. Beyond helping to share best practices in energy efficiency among member states, ECOWAS can help to fund pilot projects that promote energy efficiency in member states. It could choose to finance and sponsor these projects with counterpart funding from the nations involved with projects or with international development partners and donors.

Conclusion

The economic crises are deeply rooted in the energy crisis, as once there is low supply of energy, then a looming economic collapse can be expected. Crude oil prices kept increasing until the global meltdown, and then, energy prices had to decrease drastically. Energy crises also precipitate environmental degradation; this is seen more in developing economies where people lack cooking fuels. They tend to cut down forest resources and reserves. The equation above gives a vivid summary.

$$\text{Energy crisis} = \textbf{Economic crisis} + \textbf{Environmental crisis}$$

Energy use is today linked to economic growth and status. It is therefore proper to state here that no economy can grow far above its supporting ecological system; doing so will cause imbalances which we are witnessing in global warming and Climate change. Mankind has impacted heavily on the environment, leaving a large ecological footprint trailing behind our activities. Technological innovations have made us understand that the world is a global village. As civilized nations move towards material and energy efficiency, and then to sustainable development, they must not leave the developing nations behind. The effects of gases flared in the south of the Atlantic surely do not remain there; they reach the atmosphere and will certainly reach other places around the globe through multiplier effects. We must therefore care about what happens all over the globe:

> To each generation comes its allotted task; and no generation is to be excused to perform that task. Theodore Roosevelt.
>
> Some people who live before us paid dearly for us to be where we are today. It took the resilience of Thomas Edison to help us utilise electricity today. We must let the future generation know it must be produced and utilised efficiently.

Figure 6 tries to show us that humanity has changed its material use from resource wastage to efficiency by replacing wood fuel and animal dung as cooking

Fig. 6 historical changes in fuel

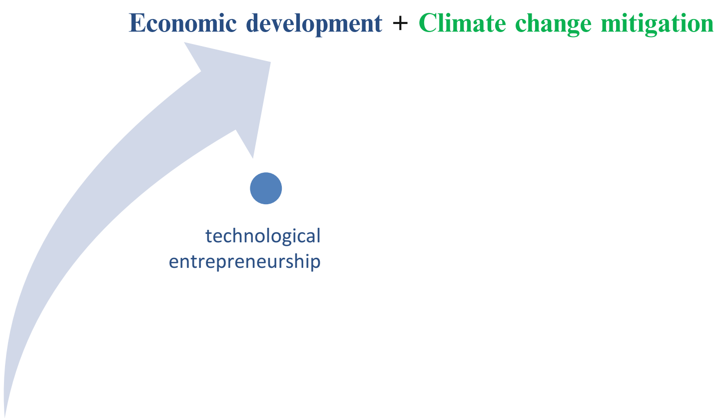

Fig. 7 Technological entrepreneurship as a solution to energy and economic crisis

fuels with coal, crude oil, and then finally with renewable energy sources today. As more developing nations try to industrialize, collective efforts must be made to ensure that they do so sustainably; otherwise, they will create common problems for all in the future. We can help by making sure developing economies have education deeply rooted in science, technology, and innovation studies with entrepreneurial good skills. Figure 7 shows that technological entrepreneurship could alter the equation above. It could change energy crisis, which in turn will after affects economic and environmental crisis. Then, the citizens of such developing countries can contribute to their national indigenous knowledge by providing quality skills and technological innovation that can be adapted into solving their local challenges. In so doing, efficiency will be achieved when technological innovations meet market gaps created by production systems (which leave no room for wastage of materials or energy losses). This will ultimately help to curb the effect of climate change.

ECOWAS as a community of developing countries should build the capacity to change the uncertainties of Climate change into manageable risks. Energy poverty is a challenge that creates opportunities to be exploited. Every risk has a positive side, and the higher the risks, the greater the reward.

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Enhancing Biodiversity Co-benefits of Adaptation to Climate Change

Kanako Morita and Ken'ichi Matsumoto

Contents

Abstract

We explore effective management of the interplay between the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD) to enhance the biodiversity co-benefits of adaptation. By using the framework of interplay management in environmental governance, this research analyzes (1) the interactions between the UNFCCC and the CBD via ecosystem-based adaptation discussions, interactions that could reduce negative impacts and enhance positive effects on biodiversity, and (2) the efforts of the relevant actors in these interactions. We show that the CBD is addressing tangible ecosystem-based adaptation issues and that the UNFCCC refers to these efforts. However, there is limited explicit collaboration between the two Conventions because of their different characteristics. The key actors who are especially important in efforts to strengthen linkages between the two

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agencies with respect to ecosystem-based adaptation are the UNFCCC and CBD secretariats; the Joint Liaison Group (JLG), which links national adaptation programs of action and national biodiversity strategies and action plans; multilateral aid agencies such as the Global Environment Facility (GEF) that serve as financial mechanisms to UNFCCC and CBD; and national government ministries that address environmental problems in developing countries and can coordinate relevant actors at the national level.

Keywords

Ecosystem-based adaptation • Interplay management • UNFCCC • CBD

Introduction

Climate change and biodiversity issues are interlinked, although they are addressed by distinct governing bodies. Climate change needs to be considered within biodiversity conservation action because climate change affects biodiversity. Similarly, aspects of biodiversity conservation must be part of climate change mitigation and adaptation because if not well planned, these activities could impact biodiversity negatively.

This chapter explores the management of interaction between climate change and biodiversity governance agents, with a focus on adaptation. Adaptation is a response to climate change, and it can influence biodiversity in positive or negative ways. Although the primary institutional frameworks of adaptation currently fall under the United Nations Framework Convention on Climate Change (UNFCCC), reducing the negative impacts and enhancing their positive effects of adaptation on biodiversity are within the purview of the Convention on Biological Diversity (CBD). Successful management of the interaction between climate change and biodiversity governance agents could maximize the positive effects of adaptation in terms of both climate change and biodiversity. This research uses the framework of interplay management in the field of international politics, which focuses on efforts by relevant actors to address and improve institutional interaction and its effects (Stokke 2001; Oberthür 2009; Oberthür and Stokke 2011).

This chapter analyzes the negotiation processes and relationships of the UNFCCC and the CBD, with a focus on ecosystem-based adaptation. Ecosystem-based adaptation applies biodiversity and ecosystem services as part of an overall strategy of response to the adverse effects of climate change (SCBD 2009). It can not only play a role in reducing climate change impacts but could provide social, cultural, economic, and biodiversity co-benefits. The CBD has been developing tangible, ecosystem-based adaptation activities, and the UNFCCC acknowledges these efforts. There is however limited explicit collaboration between them because of their different mandates, negotiation processes, and actors involved. This chapter goes on to analyze the key actors involved in efforts to improve collaboration and implementation of ecosystem-based adaptation. These actors include the UNFCCC and CBD secretariats, parties to the UNFCCC and CBD (national governments of developing countries), aid agencies, and NGOs. Our analysis identifies efforts to improve institutional interactions between the UNFCCC and CBD.

Increase Positive and Minimize Negative Effects of Adaptation on Biodiversity

In most cases, adaptation can increase positive and reduce negative effects on biodiversity through such initiatives as environmental impact assessments, technology impact assessments, or strategic environmental assessments (SCBD 2009, p. 38). In this chapter, we focus on ecosystem approaches to adaption as defined above. Ecosystem-based adaptation may include sustainable management, conservation, and restoration of ecosystems as parts of an overall adaptation strategy that hopes to achieve social, economic, and cultural co-benefits for local communities (CBD Decision X/33).

Table 1 presents examples of ecosystem-based adaptation measures that achieve co-benefits, including biodiversity. An example is mangrove conservation, which not only provides protection from storm surges, a rising sea level, and coastal inundation (thus addressing climate change issues) but also protects biodiversity and conserves the habitats and species that live and breed in mangrove areas.

Ecosystem-based approaches to adaptation have been defined and examined by the CBD. Ecosystem-based adaptation has also been reflected in UNFCCC adaptation discussion although the discussion is less extensive than that of the CBD. Ecosystem-based adaptation has been initiated by various actors in both developed and developing countries (UNFCCC 2013a). Multilateral organizations and aid agencies such as the United Nations Environment Programme (UNEP) launched the Ecosystem-based Adaptation Flagship Programme, whose activities include providing policy support and decision-making tools for policies and programs and piloting activities on the ground. The work is carried out in collaboration with numerous partners, including the United Nations Development Programme (UNDP), the International Union for Conservation of Nature (IUCN), United Nations Habitat, the Global Environment Facility (GEF), and donors, civil society organizations, and academia (UNEP 2013). Ecosystem-based adaptation projects are also implemented by aid agencies, national governments, and international NGOs. The Australian Agency for International Development (AusAID) supports a project to increase taro crop diversity in Samoa, and the World Wildlife Fund (WWF) supports a project for the Mesoamerican reef in Belize (see Table 4).

In this chapter, we analyze ecosystem-based adaptation in developing countries, which are generally more vulnerable to climate change than are developed countries, and where multiple aid agencies and international NGOs are involved. Note: ecosystem-based adaptation is an emerging concept and research is therefore constrained by limited data.

Table 1 Examples of ecosystem-based adaptation

Adaptation measure	Adaptive function	Co-benefits: Social and cultural	Co-benefits: Economic	Co-benefits: Biodiversity	Co-benefits: Mitigation
Mangrove conservation	Protection against storm surges, sea level rise, and coastal inundation	Provision of employment options (fisheries and prawn cultivation)	Generation of income to local communities through marketing of mangrove products (fish, dyes, medicines)	Conservation of species that live or breed in mangroves	Conservation of carbon stocks, both above- and belowground
		Contribution to food security			
Forest conservation and sustainable forest management	Maintenance of nutrient and water	Opportunities for recreation	Potential generation of income through: ecotourism, recreation	Conservation of habitat for forest plant and animal species	Conservation of carbon stocks
	Flow	Culture protection of indigenous peoples and local communities			Reduction of emissions from deforestation and forest degradation
	Prevention of land slides		Sustainable logging		
Restoration of degraded wetlands	Maintenance of nutrient and water flow, quality, storage, and capacity	Sustained provision of: livelihood	Increased livelihood generation	Conservation of wetland flora and fauna through maintenance of breeding grounds and stop over sites for migratory species	Reduced emissions from soil carbon mineralization
	Protection against floods or storm inundation	Recreation	Potential revenue from recreational activities		
		Employment opportunities	Sustainable use		
			Sustainable logging of planted trees		

Establishment of diverse agroforestry systems in agricultural land	Diversification of agricultural production to cope with changed climatic conditions	Contribution to food and fuel wood security	Generation of income from sale of timber, firewood, and other products	Conservation of biodiversity in agricultural landscape	Carbon storage in both above- and belowground biomass and soils
Conservation of agrobiodiversity	Provision of specific gene pools for crop and livestock adaptation to climatic variability	Enhanced food security	Possibility of agricultural income in difficult environments	Conservation of genetic diversity of crop varieties and livestock breeds	
		Diversification of food products			
		Conservation of local and traditional knowledge and practices	Environmental services such as bees for pollination of cultivated crops		
Conservation of medicinal plants used by local and indigenous communities	Local medicines available for health problems resulting from climate change or habitat degradation, e.g., malaria, diarrhea, and cardiovascular problems	Local communities have an independent and sustainable source of medicines	Potential sources of income for local people	Enhanced medicinal plant conservation	Environmental services such as bees for pollination of cultivated crops
		Maintenance of local knowledge and traditions		Local and traditional knowledge recognized and protected	
Sustainable management of grassland	Protection against flood	Recreation and tourism	Generate income for local communities through products from grass (e.g., broom)	Forage for grazing animals	Maintenance of soil carbon storage of soil carbon
	Storage of nutrients			Provide diverse habitats for animals that are predators and prey	
	Maintenance of soil structure				

Source: SCBD (2009)

Analytical Framework

The academic literature contains studies of the interactions among environmental institutions, where one institution affects the development or performance of another. Young (2002), Oberthür and Stokke (2011) and others have developed case studies of various international environmental institutions in areas such as climate change, biodiversity, ozone depletion, ocean-related issues, and trade policy. Young (2002) studied the characteristics of interactions among environmental institutions and categorized the interactions as vertical/horizontal or political/functional interplay. In contrast, Stokke (2001) and Gehring and Oberthür (2008) focused on the causal mechanisms of institutional interplay.

The research cited above focuses on institutional relationships, but does not identify factors that enable the creation of effective institutional interactions that can resolve conflicts between institutions. Recent studies of interplay management examine the governance of institutional interactions by focusing on the efforts and effects of relevant actors in addressing and improving institutional interactions (Oberthür 2009; Oberthür and Stokke 2011). This research uses an actor-centered approach and examines how conflicts can be avoided through: (1) analysis of the relationships between the UNFCCC and CBD and the interactions between these two agencies in regard to adaptation and (2) analysis of the roles of the relevant actors, including the secretariats of the UNFCCC and CBD, aid agencies, national governments in developing countries, and NGOs.

Several studies analyze the differences and similarities between climate change and biodiversity regimes for forest issues (Morgera 2011; Savaresi 2011; McDermott et al. 2012; van Asselt 2012). However, there is no research on adaptation that analyzes the contribution of actors in managing climate change and biodiversity governance.

Institutional Interactions and the Role of Actors in Adaptation

Adaptation Negotiation Under the UNFCCC and CBD

Ecosystem-based adaptation has been discussed under both the UNFCCC and CBD. The UNFCCC and CBD are part of the three Rio Conventions (the third is the United Nations Convention to Combat Desertification, UNCCD), which emerged from the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. Although the UNFCCC and CBD are sister Conventions, they have different objectives, administration, secretariats, and party members. Table 2 shows the structure and characteristics of the two Conventions.

The UNFCCC primarily focuses on climate change mitigation, particularly those issues identified in the Kyoto Protocol. However, the necessity of adaptation is also explicitly stated in the text of the UNFCCC and the Kyoto Protocol, acknowledging that climate change impact is unavoidable (Morita 2010). Adaptation has been discussed under the UNFCCC and the Kyoto Protocol in

Table 2 Structures of the UNFCCC and CBD

	UNFCCC	CBD
Establishment	Opened for signature in 1992 at the UNCED	
	Entered into force in 1994	Entered into force in 1993
Objectives	Stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system	Conservation of biological diversity
		Sustainable use of its components
		Fair and equitable sharing of the benefits arising out of the utilization of genetic resources
Administration	Under the UN	Under the UNEP
Secretariat	Headquarters: Bonn	Headquarters: Montreal
Parties	193 parties + European Union	192 parties + European Union (the USA is nonparty)
Related to adaptation	Workstream: Nairobi Work Programme, National Adaptation Programmes of Action, National Adaptation Plans, Loss and Damage	Workstream: Biodiversity and Climate Change including ecosystem approaches to adaptation
	Adaptation-related funds: Special Climate Change Fund	
	Least Developed Countries Fund	
	Adaptation Fund (under the Kyoto Protocol)	

Source: Created based on the information in UNFCCC and CBD websites

relation to: the clean development mechanism, technology transfer, research and systematic observation, capacity building, adaptation to adverse effects of climate change, Least Developed Country (LDC) assistance, national communications, and financial mechanisms. Adaptation began to receive increasing attention following the UNFCCC Conference of the Parties (COP 6) in 2000 (Morita 2010).

Currently, there are four workstreams on adaptation under the UNFCCC: the Nairobi work program on impacts, vulnerability, and adaptation to climate change (NWP), National Adaptation Programmes of Action (NAPA), National Adaptation Plans (NAPs), and the Work Programme on Loss and Damage (UNFCCC 2013b). In 2010, the Cancun Adaptation Framework resulted in negotiations on greater action, grouped into five clusters: implementation, support, institutions, principles, and stakeholder engagement. The Framework includes establishing processes for NAPs and the Work Programme on Loss and Damage. In addition to the workstreams, the Framework includes establishment of an Adaptation Committee to promote timely and coherent action under the Convention:

1. NWP: This work program is established to assist all parties, in particular developing countries, LDCs, and small island developing states, to enhance knowledge about adaptation. The NWP is undertaken under the Subsidiary Body for Scientific and Technological Advice (SBSTA) and is implemented by parties, intergovernmental and nongovernmental organizations, the private sector, communities, and other stakeholders. Currently, ecosystem-based

adaptation has been discussed under the NWP. COP 12 renamed the 5-year program of work "Nairobi work programme on impacts, vulnerability and adaptation to climate change" in 2006.

2. NAPA: This process was established in 2001 to provide LDCs the opportunity to identify priority activities that respond to their urgent and immediate needs to adapt to climate change. The LDC Expert Group provides technical support and advice.
3. NAP: This process was established under the Cancun Adaptation Framework to enable LDCs to formulate and implement national adaptation plans as a means of identifying medium- and long-term adaptation needs and developing and implementing strategies and programs to address those needs. The LDC Expert Group for NAPA also provides technical guidance and support to NAPs.
4. Work Programme on Loss and Damage: This program, also established under the Cancun Adaptation Framework, aims to consider approaches to address loss and damage associated with climate change impacts in especially vulnerable developing countries.

Article two of the UNFCCC mentions the importance of ecosystem-based adaptation, stating that "the ultimate objective of this Convention . . .is to achieve. . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change. . .."

At the UNFCCC COP 14 in 2008, Sri Lanka and Palau proposed an ecosystem approach to adaptation (IISD 2008, p. 13), and at the UNFCCC COP 16 in 2010, the Cancun Agreement was adopted. As the Agreement states, it "Invites all Parties to enhance action on adaptation under the Cancun Adaptation Framework, . . .by undertaking, inter alia, the following: . . . Building resilience of socioeconomic and ecological systems, including through economic diversification and sustainable management of natural resources" (UNFCCC Decision 1/CP.16, II paragraph 14(b)). Ecosystem-based adaptation has also started to receive attention under the NWP. In June 2011 at the UNFCCC SBSTA 34 session, the SBSTA request of the secretariat to undertake interim activities under the NWP included compilation of information on ecosystem-based approaches to adaptation (FCCC/SBSTA/2011/L.13). This information was compiled prior to the UNFCCC COP17 in 2011, and it reflected activities of the CBD. The UNFCCC also created an ecosystem-based adaptation database on its website (UNFCCC 2013a). At the COP 17, the secretariat was asked to organize workshops in collaboration with NWP partner organizations and other relevant organizations. Included was "a technical workshop on ecosystem-based approaches for adaptation to climate change, before the 38th session of the SBSTA, taking into account the role of ecosystems, including forests, in adaptation; vulnerability and impacts in ecosystems; the implementation and benefits of ecosystem-based approaches for adaptation; and lessons learned, including through the three Rio Conventions" (UNFCCC Decision 6/CP.17, paragraph 4 (b)). This workshop, organized under the NWP, was held in Dar es Salaam, United Republic of Tanzania, in March 2013 (FCCC/SBSTA/2013/2). At the subsequent SBSTA 38 meeting in June 2013, ecosystem-based adaptation was mentioned in the NWP draft conclusions (FCCC/SBSTA/2013/L.9).

Specific ecosystem-based adaptation measures have been subject to more discussion by the CBD than by the UNFCCC. At the CBD COP 7 in 2004, recorded decisions cite the potential of an ecosystem-based approach to adaptation (CBD Decision VII/15, paragraph 8), and under the CBD COP 8 and COP 9, decisions established the links between adaptation and biodiversity conservation (CBD Decision VIII/3 and IX/16). The CBD COP 10 in 2010 invited "Parties and other Governments....to consider the guidance below on ways to conserve, sustainably use and restore biodiversity and ecosystem services while contributing to climate-change mitigation and adaptation: Recognizing that ecosystems can be managed to limit climate change impacts on biodiversity and to help people adapt to the adverse effects of climate change; implement where appropriate, ecosystem-based approaches for adaptation, ...as part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities;..." (CBD Decision X/33, paragraph 8 (j)). The CBD COP 11 in 2012 addressed ecosystem-based adaptation and the NWP, encouraging parties and other governments to "...support the strengthening of inventorying and monitoring of biodiversity and ecosystem services at appropriate scales in order to evaluate the threats and likely impacts of climate change and both positive and negative impacts of climate-change mitigation and adaptation on biodiversity and ecosystem services" (CBD Decision XI/21, paragraph 6 (e)), "Encourages Parties and other Governments to... consider reviewing land-use planning with a view to enhancing ecosystem-based adaptation to climate change..." (paragraph 6 (f)), and "Requests the Executive Secretary... to... identify relevant workshops and activities within the NWP and countries' NAPs under the UNFCCC, and disseminate such information....with a view to enhancing knowledge-sharing on ecosystem-based approaches" (paragraph 7 (a)).

The first Ad Hoc Technical Expert Group (AHTEG) on Biodiversity and Climate Change, established in 2001, extended the CBD discussions. The AHTEG aimed to add technical and scientific advices for the integration of biodiversity considerations into the measures that might be taken under the UNFCCC and its Kyoto Protocol to implement mitigation and adaptation (SCBD 2003). The second AHTEG on Biodiversity and Climate Change, which convened in 2008, complied and described the characteristics of ecosystem-based adaptation in the CBD Technical Series (SCBD 2009).

The CBD has attempted to add ecosystem-based adaptation to the discussion on the NWP and has attempted to unite the two Conventions in the ways in which they address adaptation. In the UNFCCC SBSTA 31 Plenary (COP15) in 2009, the CBD stated at the conclusion of the work of the second AHTEG on Biodiversity and Climate Change, "ecosystem-based adaptation is not sectorally limited, but addresses potential adaptation needs across many sectors," "ecosystem-based adaptation is highly relevant because it: can be applied at all levels; may be more cost-effective and more accessible to rural or poor communities than measures based on hard infrastructure and engineering; and can integrate and maintain traditional and local knowledge and cultural values," and "ecosystem-based adaptation approaches can also contribute to climate change mitigation by conserving or enhancing carbon stocks and reducing emissions caused by ecosystem degradation and loss" (Statement of the CBD at UNFCCC SBSTA 31 Plenary). Furthermore, the final report of the AHTEG on Biodiversity and Climate Change (SCBD 2009) was transmitted to the UNFCCC COP 15 by the CBD COP 9 with a view to convening a joint meeting of the two bureaus (CBD Statement at the UNFCCC SBSTA 31 Plenary).

At the UNFCCC COP 16, the CBD highlighted the outcomes of its COP 10, stating that the discussions focused on a number of issues related to the NWP, including the development of joint activities at national levels, the promotion of ecosystem-based approaches for adaptation and mitigation especially for protected areas, and improving information on the impact of climate change on biodiversity (CBD Statement at the UNFCCC SBSTA 33 Plenary). The CBD also invited the UNFCCC to collaborate with it (CBD Statement at the UNFCCC SBSTA 33 Plenary).

Thus, although there is limited explicit collaboration between the UNFCCC and the CBD, the CBD has actively discussed ecosystem-based adaptation, and the UNFCCC has acknowledged CBD's work. Table 3 summarizes the adaptation discussions under the UNFCCC and CBD.

Efforts of the Relevant Actors to Support Interaction

We next analyzed the contribution of relevant actors in efforts to encourage discussion and interaction between the UNFCCC and CBD on ecosystem-based adaptation. The actors are the UNFCCC and CBD secretariats, multilateral and bilateral donors, national governments in developing countries, and NGOs.

Table 4 presents examples of ecosystem-based adaptation activities in developing countries. This table illustrates the many actors involved in projects, and their efforts are analyzed in terms of the identified activities.

Secretariat Efforts

Secretariats are important for improving the interactions between the UNFCCC and CBD vis-a-vis ecosystem-based adaptation, but they currently play differing roles. The CBD secretariat has developed significant influence in international negotiations and cooperation (Siebenhüner 2009), while the UNFCCC secretariat has not promoted the political ideas of the committee or proposed specific technical approaches (Busch 2009).

The Joint Liaison Group (JLG) was established in 2001 as an informal forum among the three Rio Conventions for exchanging information, exploring opportunities for synergistic activities, and increasing coordination (CBD 2013). The JLG comprises the members of the secretariats, the executive secretariats, and the officers of scientific subsidiary bodies (CBD 2013). The JLG clearly has the

Table 3 Adaptation discussions under the UNFCCC and CBD

UNFCCC		CBD	
COP 6–9 (2003)	Adaptation issues were discussed under various agendas. Adaptation begins to receive more attention following COP 6 (2000)		
COP 10 (2004)	Decided the Buenos Aires program of work on adaptation and response measures, which describes ways to respond to the adverse effects of climate change (UNFCCC Decision 1/CP.10)	COP 7 (2004)	Stated that the application of an ecosystem approach could facilitate the formulation of climate change mitigation and adaptation projects that also contribute to biodiversity conservation and sustainable use at the national levels (CBD Decision VII/15)
COP 11 (2005)	Adopted a 5-year work program on the SBSTA on impacts, vulnerability, and adaptation to climate change (Decision 2/CP.11)		
COP 12 (2006)	Renamed the program to NWP (FCCC/CP/2006/5)	COP 8 (2006)	Parties, other governments, and so on are encouraged to development rapid assessment tools for the design and implementation of biodiversity conservation and sustainable use activities that contribute to adaptation (Decision VIII/30)
COP 13 (2007)	Decided to launch "a comprehensive process to enable the full, effective and sustained implementation of the Convention through long-term cooperative action, now, up to and beyond 2012," including addressing "enhanced action on adaptation" (Decision 1/CP.13)		
COP 14 (2008)	*Sri Lanka and Palau, speaking also for Micronesia and the Marshall Islands, proposed an ecosystem approach to adaptation*	COP 9 (2008)	Showed the proposals for the integration of climate change activities within the work programs of the Convention, including conducting in-depth reviews of the work programs by considering such as the contribution of biodiversity to adaptation and measures that enhance the adaptive potential of components of biodiversity (Decision IX/16)

(*continued*)

Table 3 (continued)

UNFCCC		CBD	
COP 15 (2009)			
COP 16 (2010)	Decided to establish the Cancun Adaptation Framework including establishing NAPs process, Work Programme on Loss and Damage, and Adaptation Committee (Decision 1/CP.16)	COP 10 (2010)	Mentioned the role of ecosystem-based adaptation and call for the integration of ecosystem-based adaptation into relevant strategies and careful consideration of different ecosystem management options and objectives (Decision X/33)
COP 17 (2011)	Decided the structures and functions of the Adaptation Committee (Decision 2/CP.17). Adopted COP decisions on NWP (6/CP.17), NAPs (5/CP.17), and Work Programme on Loss and Damage (7/CP.17)		
	NWP: *secretariat and NWP partner organizations, etc., are requested to organize a technical workshop on ecosystem-based approaches for adaptation*		
COP 18 (2012)	Adopted COP decisions on approaches to address loss and damage (Decision 3/CP.18), work of the Adaptation Committee (11/CP.18), and NAPs (12/CP.18)	COP 11 (2012)	Decisions touch on ecosystem-based adaptation and NWP such as encourages parties to support strengthening inventorying and monitoring of biodiversity and ecosystem services to evaluate both positive and negative impacts of climate change mitigation and adaptation on biodiversity and ecosystem services. Also requests the Executive Secretariats to identify relevant workshops and activities within the NWP and countries' NAPs under the UNFCCC (CBD Decision XI/21)

potential to strengthen the links between the UNFCCC and CBD secretariats concerning ecosystem-based adaptation.

The COPs of the three Conventions have recognized that adaptation is an area of importance (JLG 2004). The executive secretaries of each Convention identify adaptation, capacity building, and technology transfer as priority areas for their discussion (JLG 2004). The three secretariats have also identified options for

Table 4 Examples of ecosystem-based adaptation in developing countries

Name	Country	Ecosystem	Name of implementing institution
Responding to shoreline change and its human dimensions through integrated coastal area management	Mauritania, Senegal, Gambia, Guinea Bissau, Cape Verde	Marine and coastal	UNDP, GEF, UNESCO
Enhancing adaptive capacity in semiarid mountainous regions, Bolivia	Bolivia	Mountain, forest, and woodland	The Netherlands Climate Assistance Programme (NCAP)
The CEIBA-PILARES project	Ecuador and Peru	Forest and woodland	Nature and Culture International
Coping with drought and climate change in the Chiredzi district	Zimbabwe	Agriculture, rangelands, and grasslands	Government, UN Agency
Integrated National Adaptation Plan – Colombia highland ecosystems	Colombia	Mountain; Inland water	GEF; World Bank; Conservation International
Drought-resistant agriculture in El Salvador	El Salvador	Agriculture	Red Cross, World Food Programme
Community-based coastal habitat restoration (“Green Coast Project”)	Indonesia, Sri Lanka, India, Thailand, and Malaysia	Marine and coastal, forest and woodland	Wetlands International, Both Ends, WWF, IUCN
Integrating agroforestry practices in the farming system in Grenada	Grenada	Agriculture, mountain	Government of Grenada
Integration of climate change risk and resilience into forestry management (ICCRIFS)	Samoa	Forest and woodland	UNDP, GEF, Government of Samoa
Jordan Valley Permaculture Project	Jordan	Agriculture	National Center for Agricultural Research and Transfer of Technology, Jordan; Permaculture Research Institute (PRI) of Australia
Kikuyu Escarpment Forest	Kenya	Forest and woodland	Birdlife, Kenyan Forestry Service
Kimbe Bay: scientific design of a resilient network of marine protected areas	Papua New Guinea	Marine and coastal	The Nature Conservancy
Assessing the Impacts of Climate Change on Madagascar’s Biodiversity and Livelihoods	Madagascar	Forest, marine and coastal	Government of Madagascar, USAID, Conservation International, WWF

(*continued*)

Table 4 (continued)

Name	Country	Ecosystem	Name of implementing institution
Using the Maya Nut Tree to increase tropical agroecosystem resilience to climate change in Central America and Mexico	Nicaragua, Guatemala, El Salvador and Mexico	Forest and woodland, agriculture	Maya Nut Institute
Adapting to climate change in the Mesoamerican Reef	Belize	Marine and coastal	WWF
Coping with drought and climate change, Mozambique	Mozambique	Agriculture, rangeland, and grassland	UNDP
Nomadic herders: enhancing the resilience of pastoral ecosystems and livelihoods	Mongolia and Russian Federation	Mountain, rangeland, and grassland	UNEP/GRID-Arendal, Association of World Reindeer Herders, UArctic EALAT Institute
Orito Ingi Ande Medicinal Plants Sanctuary	Colombia	Forest and woodland	Government of Colombia, local communities
The Pangani River Basin Management Project (PRBMP)	Tanzania	Inland water, agriculture	Pangani River Basin Management Project, IUCN, UNDP
Rio de Janeiro's Community Reforestation Project	Brazil	Urban, forest and woodland	City of Rio
Conservation and management of high altitude peatlands of Ruoergai Marshes for water security and climate change adaptation	China	Mountain, inland water	Wetlands International
Maintenance of hydropower potential in Rwanda through ecosystem restoration	Rwanda	Inland water	Government of Rwanda
South Africa: ecosystem-based planning for climate change	South Africa	All	Government of South Africa
Community-based rangeland rehabilitation	Sudan	Rangeland and grassland, agriculture	UNDP, GEF
Adaptation to climate change impacts in the Syunik Mountain Forest Ecosystems of Armenia	Armenia	Forest and woodland, mountain	GEF, UNDP, Government of Armenia
Increasing Taro Crop Diversity	Samoa	Agriculture	Secretariat of the Pacific Community, AusAID, Australian Centre for International Agricultural Research

(*continued*)

Table 4 (continued)

Name	Country	Ecosystem	Name of implementing institution
Tonle Sap	Cambodia	Forest and woodland, inland water	Conservation International, Government of Cambodia
Climate Change Governance Capacity: Building Regionally and Nationally Tailored Ecosystem-Based Adaptation in Mesoamerica	Mexico, El Salvador, Costa Rica, Panama	Marine and coastal, agriculture, inland waters	Federal Environment Ministry of Germany, IUCN
Ecosystem-Based Adaptation in Marine, Terrestrial, and Coastal Regions as a Means of Improving Livelihoods and Conserving Biodiversity in the Face of Climate Change	Brazil, Philippines, South Africa	Marine and coastal; forest and woodland; agriculture; inland water	Federal Environment Ministry of Germany, Conservation International Foundation

Source: UNFCCC 2013a

improving cooperation, including: (1) the promotion of complementarity among the national biodiversity strategies and action plans (NBSAPs) under the CBD, national action programs of the UNCCD, and the UNFCCC NAPA for LDCs; (2) the development of joint work programs or plans, joint international workshops, and joint capacity-building activities (including training and local, national, and regional workshops to promote synergy in implementation); and (3) case studies on interlinkages (CBD 2013). In 2007, at the seventh JLG meeting it was agreed that an information note on adaptation activities, plans, and programs adopted within the framework of each Convention should be drafted (JLG 2007).

The degree of willingness to enhance links between the UNFCCC and CBD executing secretariats is different: in general, the CBD more actively connects UNFCCC and CBD processes. For example, at the tenth JLG meeting in 2010 the Executive Secretary of the CBD invited his counterparts at the UNFCCC and UNCCD to convene a high level dialogue between themselves and the Secretary General at the CBD COP 10. He also shared the CBD proposal for a joint work program between the three Rio Conventions and a proposal to have an extraordinary meeting of the Rio Convention COP (JLG 2010).

Although the UNFCCC is generally passive about linking the two processes, it admits the importance of interaction on specific topics like adaptation. In 2010, also at the tenth JLG meeting, the Executive Secretary of the UNFCCC expressed concern about the CBD proposals for a joint work program and an extraordinary meeting of the Rio COPs. The concern was that the proposals would infringe on the mandate of the UNFCCC secretariats and that the topic of adaptation is still under active negotiation. Nevertheless it was acknowledged that focusing on specific topics can move the synergies agenda forward and that the NAPA, NBSAP, and national action programs of the UNCCD may be conducive to the promotion of such synergies (JLG 2010).

Although the JLG does not explicitly address ecosystem-based adaptation, the Group is important in linking the adaptation work of the UNFCCC and CBD secretariats. Further, the JLG links the works of NBSAP and NAPA, which are vital for strengthening ecosystem-based adaptation discussions.

Donor Efforts

Although the number of ecosystem-based adaptation programs and projects remains limited, multilateral aid agencies such as the GEF and the World Bank and bilateral aid agencies such as the United States Agency for International Development (USAID) and AusAID have engaged in research and implementation of ecosystem-based adaptation. In this section, we describe the efforts of both multilateral and bilateral aid agencies.

With regard to multilateral aid agencies, the GEF (see chapter "▶ Financing Adaptation to Climate Change in Developing Countries" in this handbook), serving as the financial mechanism of the UNFCCC and CBD, plays a vital role implementing ecosystem-based adaptation and linking the two Conventions. In 2004, at the fifth JLG meeting, the secretariats of the Rio Conventions discussed adaptation, capacity building, and technology transfer. This discussion was in preparation for an informal meeting with the GEF CEO (JLG 2004). The point was made that "synergy (among the objectives of the three conventions in adaptation activities) can be promoted through meetings between the Executive Secretaries of three conventions, the GEF and the Implementing Agencies, and further supported through cooperation between the Scientific and Technical Advisory Panel (STAP) of the GEF, and the respective scientific and technical subsidiary bodies of the conventions" (JLG 2004). In 2012, the GEF developed *Operational Guidelines on Ecosystem-based Approaches to Adaptation* (GEF/LDCF.SCCF.13/Inf.06) which assists agencies and project proponents that seek aid through the Least Developed Countries Fund or the Special Climate Change Fund. The GEF has supported ecosystem-based projects such as Adaptation to Climate Change Impacts in the Syunik Mountain Forest Ecosystems of Armenia and Integrated National Adaptation Plan: Colombia Highland Ecosystems (see Table 4).

Furthermore, the implementing agencies of the GEF such as the World Bank, the UNEP, and the UNDP are also actively engaged in research and projects on ecosystem-based adaptation. World Bank projects and programs support biodiversity conservation and the protection of natural habitats and ecosystem services, thereby contributing to effective mitigation and adaptation strategies (World Bank 2009). Other organizations including the International Union for Conservation of Nature, United Nations Habitat, as well as donors, civil society organizations, and academia have established ecosystem-based adaptation flagship programs (UNEP 2013).

Bilateral aid agencies and countries such as the Netherlands and Germany support ecosystem-based adaptation activities. The USAID supports the ecosystem-based adaptation project Assessing the Impacts of Climate Change on Madagascar's Biodiversity and Livelihood, and AusAID supports the Increasing

Taro Crop Diversity project. Although the number of projects funded by both multilateral and bilateral donors is limited, the ecosystem-based adaptation activities of bilateral donors are more often confined to specific areas and sectors, than those of multilateral aid agencies like the GEF (UNEP 2013). Bilateral aid agencies also lack the comprehensive guidance and strategy on ecosystem-based adaptation supports and implementation and have less influence in discussions of the UNFCCC and CBD.

National Government Efforts

Several developing countries are beginning to discuss ecosystem-based adaptation activities. Although it is early to evaluate their efforts in promoting ecosystem-based adaptation and linkage between the UNFCCC and CBD, national ministries with environmental mandates in developing countries are likely to play a significant role.

Although a number of industry or sector-specific ministries are involved in adaptation issues (e.g., Ministry of Agriculture of Grenada, Ministry of Agriculture and Fisheries of Samoa, and Kenya Forest Service), many of the ecosystem-based adaptation projects implemented in developing countries are funded by multilateral and bilateral donors and are likely to be endorsed and managed by the national ministries that address environmental problems (e.g., Environmental Management Agency of Zimbabwe, Ministry for the Environment and National Natural Parks of Colombia, and Ministry of Natural Resources and Environment of Samoa).

Cambodia's Ministry of Environment approves and supports projects such as ecosystem-based approach to integrate climate change-resilient livelihoods and floodplain management for the Tonle Sap supported by Conservation International and ecosystem-based adaptation approach to climate change along the Mekong River (Kratie Province in Cambodia) supported by the WWF (Cambodia's Ministry of Environment 2013). Examples in other countries include Integration of Climate Change Risk and Resilience into Forestry Management project in Samoa, executed by Samoa's Ministry of Natural Resources and Environment through supports from UNDP (Samoa's Ministry of Natural Resources and Environment 2013), and Adaptation to Climate Change Impacts in the Syunik Mountain Forest Ecosystems of Armenia, executed by the Ministry of Nature Protection in Armenia. The ministry that addresses environmental problems is likely to be a key to supporting ecosystem-based adaptation in developing countries, because it is usually the focal point of the UNFCCC and the CBD, and has the capacity to both coordinate actors at the national level and to help link the UNFCCC and CBD.

NGO Efforts

Many international NGOs working in nature conservation actively support and implement ecosystem-based adaptation in developing countries, including the World Wildlife Fund, Nature Conservancy, BirdLife International, CARE, and Conservation International. Conservation International is supporting ecosystem-based adaptation projects, such as the Tonle Sap project in Cambodia (see above), the Integrated National Adaptation Plan (Colombia highland ecosystems), and

Ecosystem-Based Adaptation in Marine, Terrestrial, and Coastal Regions as a Means of Improving Livelihoods and Conserving Biodiversity in the Face of Climate Change projects in Brazil, Philippines, and South Africa.

Such international environmental NGOs are actively encouraging ecosystem-based adaptation activities, but their support and activities are limited to specific areas or they play only a subsidiary role of multilateral and bilateral aid agency support. NGOs therefore have limited influence in strengthening links between the UNFCCC and CBD on adaptation.

Conclusion

Ecosystem-based adaptation, which has the potential to improve biodiversity conservation and reduce climate change impacts simultaneously, is addressed by both the UNFCCC and CBD. This chapter explores the management of the interaction between climate change and biodiversity governance, which could enhance ecosystem-based adaptation efforts and maximize the positive effects of adaptation on both climate change and biodiversity. This research used the conceptual framework of interplay management in international politics.

This chapter shows that the CBD has been involved in a greater number of tangible ecosystem-based adaptation activities than the UNFCCC, and coordinated ecosystem-based adaptation dialogue between the UNFCCC and CBD has been attempted. However, they are not fully coordinated because of the different characteristics of the two Conventions.

To promote ecosystem-based adaptation and improve collaboration between the UNFCCC and CBD, this research analyzed how the key actors can develop adaptation discourse and strengthen the links between the two UN Conventions when approaching the topic. The study suggests that to enhance links between the two Conventions, it is important to involve: the secretariats of UNFCCC and CBD, the JLG that links NAPA and NBSAP, multilateral aid agencies like the GEF that serve as financial mechanisms to the UNFCCC and CBD, numerous key actors, and the various national government ministries that address environmental problems in developing countries and who can coordinate relevant actors at the national level.

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Environmental Law, Public Policies, and Climate Change: A Social-Legal Analysis in the Brazilian Context

Thiago Lima Klautau de Araújo

Contents

Abstract

This chapter aims to analyze the laws and public policies in relation to climate change in Brazil, its implementation, and concrete results. Through a review of legislation and state of the art, this chapter gives evidence to the positive and negative interventions of the public policies since the 1950s until the present moment, using some examples, such as the bad initiative of construction of roads that promoted the deforestation and the good work made in Paragominas, Pará, to reduce environmental degradation and deforestation. As results, this chapter proposes a new perspective of the environmental law and reveals its importance in order to cope with the challenges of climate change and environmental issues, in an integrative way. In order to do so, it seeks to integrate society and governments' efforts to make possible the changes in the present climate situation, as it has been made in some isolated cases, such as Paragominas.

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Climate change • Environmental law • Greenhouse gases emission • Public policies • Sustainable development

Introduction

Currently the approach to climate change focuses on technical issues and possible solutions for reducing the emission of greenhouse gases. Rising chances of international agreements and treaties are one of the, or perhaps the only, alternatives to the reformulation of the paradigm of the relationship between man and nature.

Little is said about the importance of environmental legislation and regional public policies as an alternative solution. It happens that, while it awaits a global decision, if nothing is done at national or local areas, the climate change issue is getting worse. International law is essential to resolve the issue, but alone will not take effect.

This is because law is an area full of meanings that makes sense to those related to a particular reality and so is considered a local knowledge (Geertz 1983). This chapter tries to rescue the importance of law and public policies for the solution of climate change problems, understanding that both are essential for achieving a positive or negative response.

Having as context the legal and legislative axe and the one of public policies, as a way to define, understand, and deal with the climate changes, this chapter was organized into three complementary parts. The first part is an overview of environmental issues discussed globally since the 1970s. The second part deals with the Brazilian environmental legislation and brings some challenges and inconsistencies between theory and practice. The third part discusses the need for the implementation of sustainable development as a tool for equalization of climate change problems; points out the good example of Paragominas, Pará; and discusses the importance of an integrated action across the whole society.

At all points, it is evidenced the need of a multidisciplinary and interdisciplinary analysis, where natural and social sciences are considered sources of environmental law, but it can also be an valuable tool for the practical implementation of the acquired knowledge in those areas.

Climate Change and Legislation: Old and New Environmental Problems That Societies Have to Deal with

Nowadays, climate change is recognized as the major environmental problem and has long been a matter of global concern of societies. Climate change public policies express the formal position of governments, somehow synthesizing scientific contributions, the political positions, and economic, social, and cultural constraints, “mainly emphasizing the mitigation and adaptive processes to CC and the possibilities of intervention at the level of ecosystems and human actions” (Alves et al. 2014).

In the public discourse, the debate on the need for change in public policy and on what role business and society has to perform in order to prevent the progression of global warming or to develop the mitigation of impacts caused by climate change is usual, among other phenomena associated with it. In international agreements and conventions, this is a very recurrent theme, in which countries commit themselves to freely accept targets for reducing the emission of greenhouse gases.

This innovation in discussions about environmental issues has resulted, around the 1970s and the 1980s, from the realization of the fact that the planet could, actually, join an unprecedented environmental crisis, caused by human activity, and whose main target would be mankind itself. In the words of Édis Milaré (Milaré 2009, p. 171):

> The sustainability of the planet is, without doubt, in the hands of man, the only being capable of, with his actions, break the dynamic equilibrium produced spontaneously by the interdependence of the forces of nature and modify the regulatory mechanisms that, under normal conditions, maintain or renew natural resources and life on Earth.
>
> It is not to be against progress, but to promote and harmonize the economic and social development with minimum environmental requirements, using and conserving the natural resources and commiserating synchronously (at the present time) and diachronically (through successive times) with all humanity. The fate of future generations is thus in the hands of present generations.

It is true that such international laws have the mission of transformation of the global mentality. But it is also true that the attention given to them is not the most satisfying and does not even make big differences in the situation.

The Kyoto Protocol, for example, was a very positive initiative in theory, but in practice it did not bring great results, since most countries did not comply and will not be able to meet its goals and others do not even come to sign it, as the United States.

The decrease or increase in the emission of greenhouse gases turns out to be much more related to public policies of national of local governments than actually to international agreements or treaties.

To understand the legal systematic of climate change and what is being done to combat them through laws, it is necessary to first understand the environmental legislation.

The specific case addressed in this chapter is that of Brazil, whose federal legislation on environment has many commendable points, but its application in everyday life does not get the expected results. This could end up meaning that a country that has enormous potential to be strategic and decisive in mitigating the effects of the uncontrolled environmental situation, end up turning over a polluter country.

Brazil's Environmental and Legal Contexts

The environmental issue in Brazil presents a slightly different situation from the global context. Despite being one of the first countries to formalize strict laws in the sphere of protection of environment, its territorial extent, the lack of political will and oversight, and insufficient resources for maintenance and expansion of certain state measures preclude effective implementation of law.

Already in 1967 was the creation of the Law n. 5197, which deals with the protection of wildlife (Brasil 1967). Many other laws came before the 1980s, a period in which there was a spread of environmental discourse, however, without actually producing effects in the real world.

What is considered the major mark in the Brazilian environmental legislation, and particularly interesting in this analysis of climate change, is the creation of the Law n. 6938, of August 31, 1981, which established the National Environment Policy (Brasil 1981).

This law provides incentives for environmental protection and defense against pollution, in order to balance the environment and preserve the biota, air, natural resources, etc. Despite not specifically addressing climate change in the conceptualization of the law, one can understand that they fall into the category of environmental degradation (Art. 3, II), as denoting "adverse change in the characteristics of the environment."

There is also needed to emphasize that some principles in the existing Law n. 6938/81 are related directly to the combat against climate change. They are presented in Art. 2 of that law and are listed as items. Let us look at the most important for this issue: I, government actions to maintain the ecological balance, considering the environment as a public asset to necessarily be secured and protected in order to allow its collective use; II, rationalization of land use, water, and air; VI, encouraging study and research oriented to the technologies for the rational use and protection of environmental resources; VII, monitoring the state of environmental quality; and X, environmental education at all levels of instruction, including community education, aiming to enable communities to participate actively in environmental protection.

It happens that this statute, although advanced for the time, only received regulation nearly nine years after its enactment, with the Decree 99.274/90 (Brasil 1990), which brought the form with which the National Environmental Policy could be implemented. For nine years, the law has had its effectiveness limited by the fact that it provided "what to do," but did not provide "how to do."

So it has been the rhythm of environmental policies in Brazil and is no different in relation to climate change. Emission control is regulated by the National Council of the Environment – CONAMA – through resolutions (a kind of normative with legal value reduced, compared to the laws). This greatly hinders the access of citizens to the rules, because it is necessary that it has a very specific legal knowledge to seek regulations conducted by environmental agencies.

However, this is not a prediction of the 1988 Constitution (Brasil 1988). In its Art. 225, the Constitution says: "Everyone has the right to an ecologically balanced environment, property of common use to people and essential to a healthy quality of life, imposing upon the Government and the community the duty to defend and preserve it for present and future generations." This is called the "principle of participation," which talks about the need for civil society to participate in the preservation, discussions, decisions, and surveillance.

This provision is important, but with the way it operates the Brazilian government today, it has not been fulfilled as it should. How to participate if the population has no access to effective legislation and regulation? How to help in the preparation of laws and regulations, if the competent organs are dressed of technicality but are influenced by economic power?

The Brazilian environmental doctrine (Milaré 2009, p. 194) states that there are three forms of popular participation in the protection of the environment:

> The planning and management of the environment are thus shared between the Government and society, since the environment as a resource for the development of mankind, is, of course, one of the highest expressions of the "common good."
>
> There is the need therefore to examine in what extent the Brazilian legislation contemplates public participation in environmental protection.
>
> Álvaro Mirra, in excellent exposition on the subject, points out three basic means by which social group can act:
>
> (i) Participating in the process of creating the Environmental Law;
> (ii) Participating in the formulation and implementation of environmental policies, and
> (iii) Acting through the judiciary.

However, it is almost impossible to have direct participation of the population in environmental issues. Not to be long on a subject that is important to this chapter, but it is not your main theme, we will analyze the situation of acting through the judiciary. There are five types of judicial actions, which are very rare to be used by the population. The main reasons for this are related to technical or specific legal issues (for example, it is difficult to find a lawyer specialized in environmental law or afford to pay one), and the legitimacy to propose a lawsuit in this field.

Not only the citizens do not have money to afford the costs of a lawsuit, as in almost all cases, the population does not know where to turn. The five possible actions are: direct action of unconstitutionality of a law or normative act; public civil action; popular action; collective writ; and writ of injunction. In the large majority of cases, the active role (legitimacy) is carried by the Public Ministry, which overloads the prosecution, and does not solve the situation. One has to make the observation that despite not being legitimized by law, doctrine and jurisprudence can claim to be bringing collective writ by the Public Ministry.

This reflects that although the five judicial means are celebrated by the doctrine (that considers them a meaningful intervention of population), in practice this popular participation through judiciary does not exist. One of the reasons that explain this situation is amount of bureaucracy to sue with a direct action of unconstitutionality, popular action, or writ of injunction. It is very common that people would rather give up before the action. In most cases, citizens don't know who are the authorities that have the legitimacy to propose the lawsuit.

This is one of the types of political influence on the environmental determination, and they exist in all forms of public policies for the environment.

There is much political influence in the decisions of an environmental nature that Brazil has limitations for emissions of harmful gases to human health, such as carbon monoxide, but has not yet established limits to vehicular emission of greenhouse gases such as carbon dioxide. The lack of this regulation is the opposite of all global policies aimed to minimize the degradation of the environment. In addition to this, the lack of emission control does not allow that cars circulating in Brazil are more economical and efficient, which, besides polluting the atmosphere and harming the climate, imposing more costs to Brazilians, both in private cars or public transport.

Regulating vehicle emissions is not as complicated as it sounds, even in the case of the Brazilian automotive industry. The manufacturing facilities in Brazil produce engines for several countries that have already established emission limits. The Brazilian automakers have the technology to build more economical engines, but they do not make them available to the domestic market due to a possible decrease in the profit margin, as the pieces for more efficient cars encumber production. As the cars sold in Brazil are already the most expensive in the world, market hardly would accept higher prices, which would force declining corporate earnings.

Something that is urgent is being stalled by economic interests. Since the 1980s there are discussions about the need to reduce vehicle emissions of carbon dioxide, but governments do not show concern in addressing this demand. Environmental congresses invoke that need for at least 10 years, but there is no practical advance in the regulations. Anfavea (National Association of Automobile Manufacturers) presses the government to postpone the limitations and thus gain time, as Anfavea did to delay turning airbags into required items of security, for example, or to increase the taxes for imported cars. Attitudes like these, as well as highly reprehensible, are extremely harmful to the environment, consumers, and the market.

We must mention that it is very important to change habits and tailor products to the needs of preserving and avoid catastrophic climate changes to come, and for this reason, the limitation of vehicular emissions of pollutants of all kinds is so necessary. More economical and efficient cars pollute less, and if they do not solve completely the problem, they would help to mitigate some aspects of climate change.

Another element that draws attention in Brazil is the kind of pollutant emissions. There are considerable emissions in agricultural activities, in deforestation, fires, transport, power generation (since the policy established by the governments of Lula and Dilma directed to energy sources privileging thermoelectric power plants), etc.

The main source of emissions of greenhouse gases in Brazil is deforestation that is being decreased for five consecutive years, and in 2012 Brazil registered the least amount of these gases in 20 years. The worrying fact is that the high emissions in all other branches mentioned above was alarming, especially in the energy sector with an increase of 126 % between 1990 and 2012 (Miranda 2013).

To get even worse this scenario, after years of decline in deforestation, between 2012 and 2013, there was an increase of 28 % in the deforested area (Miranda and Nublat 2013), which incurs more emissions and worsening climate change.

The Brazilian Federal Government fails to invest in environmental enforcement, not to restrain conduct detrimental to the environment and not to encourage the prevention of environmental damage. It does not stimulate popular participation in environmental protection and also does not promote environmental education in schools. In the long term this is extremely harmful, since mankind races against time and tries to remedy the damage already installed on the grounds of lack of appreciation of the importance of the environment and climate balance.

However, some measures have enabled local governments amazing changes in this pessimistic scenario.

The Effects and Side Effects of Public Policies

In addition to the principles laid down in the Constitution, it is necessary to articulate public policies in all sectors in order to make possible to solve social problems, protect the environment, and develop the economy.

These three points mentioned above are the basis for sustainable development. It is hard to achieve the point of balance between them, but it enables real progress as it combines advances in all relevant areas to society.

Brazilian public policies in general, have failed in recent years, especially considering the catastrophic results of federal government interventions since the end of the 1950s until the present time.

On becoming president of Brazil, Juscelino Kubitschek – loved or hated political figure in Brazil – motivated by interests which are not ours to comment on this chapter, encouraged what would be the biggest mistake of Brazilian history since the proclamation of the republic: the destruction of railroads and their replacement by roads. Began the works starting in Brasilia and trying to interconnect it with other cities, Juscelino did the federal government getting numerous debts – which are still being paid – for the construction of several roads to major Brazilian cities, called BRs.

The intention was to develop the national automobile industry, which until then only produced the "refined" Romi Isetta (version BMW Isetta) and Fusca (VW Beetle), both with 100 % of imported pieces. Indeed, the creation of highways has greatly increased the production, sale, and diversity of national car models; however, the negative effects were extremely negative.

There was degradation of the Amazon forest, with numerous fires, eliminating several green areas and the beginning of landholdings in the region. This degradation affected strongly the environmental biodiversity, delivered over the years, at least hundreds of millions of tons of carbon into the atmosphere.

Some of these roads were created within areas of native vegetation, native forest that is absolutely necessary for the ecological balance. It happens that these roads ultimately attract people who did not have land in other regions of Brazil, to occupy marginal lands to BRs. The state of Pará was one of the most affected and still suffers from the almost uncontrollable deforestation. The majority of municipalities in this federal unit were created as a consequence of this road expansion, because there were no such settlements before installation of roads.

One of these newborn cities is Paragominas, Pará, near the BR-010, called the Belém-Brasília road. Planned from one of the defeated projects for the construction of the Federal Capital, Paragominas was a small town, but because of its diverse forest, mineral resources and its strategic location began growing faster than his frame stand (like Belém after the construction of the highway), and the chaos was settled.

Paragominas was known internationally by the number of homicides, by the increasing violence, environmental degradation, and the high rate of deforestation. As a way of getting this scenario worse, another activity developed in the region was the production of charcoal, highly polluting and greenhouse gas emitter.

This city was the example of chaos and lack of public intervention, both in environmental and climate issues. The emission of gases arising from fires and charcoal production contributed not only to the increase of global temperature but also to the occurrence of respiratory problems in the population, especially in the summer season (in the Amazon there is only summer and winter), when the proliferation of smoke coming from those predatory activities was common.

However, with a well-succeeded articulation between the city government, the state government, farmers, and population, Paragominas radically changed its course. Currently, it is known as a fine example of the performance of the government that can change the reality of a place and positively modify the relationship between man and nature. The deforestation started to be near to zero, and the deforestation area was 0.032 % in 2012 (Instituto Ethos et al. 2013).

Government intervention occurred in several areas, as has been well elucidated by a Brazilian magazine of general circulation (Barbosa 2011):

> Over time, the project that was born of a social pact was expanding partnerships with government institutions and the private sector. Then Paragominas decided to be the first municipality in Pará to monitor and verify deforestation, in a partnership with the Institute of Man and Environment of Amazon (Imazon). In one year they achieve a reduction of almost 90 % in deforestation. In March 2010, the Ministry of Environment announced the exclusion of Paragominas from the list of the largest Amazon loggers.
>
> Currently, the city has 66 % of preserved forests and vast extension of Permanent Protection Areas in agricultural properties. Inspired by the social and environmental transformation of Paragominas, 94 other municipalities of Pará today develop similar initiatives.
>
> "Before, to grow, we were destroying the forest. Now, we are the municipality that restores more green areas in the Amazon," boasts Demachki. The importance of preserving the environment is diffused by a program of environmental education in schools. "It is our mission and converge arms and minds towards social development and environmental preservation," says.

This successful example was adopted as a reference to 11 other cities in Pará (Carvalho 2011), which joined the Green Cities Program of the state government in order to get out of the list of cities that most deforest the Amazon forest.

The most important lesson that can be drawn from the case of Paragominas is that it is possible to recover environmentally highly degraded areas, help the planet, and interfere positively to the reduction of global warming, without losing the ability of economic growth. The ones who visit the city have a good surprise to find that it is a lively, cheerful, well-urbanized, organized city, with a dynamic and growing economy, where the population have excellent quality of life.

However, such results would be much easier to achieve if they would not be dependent on the political will. What occurred in that city is a reflection of a good relationship between all sectors of society, with the collective effort to balance a state of degradation.

The global challenge of public policies related to climate change is exactly the same that was in Paragominas: changing paradigms of using natural resources so that people can live better. Although, in a global scale, local differences between political groups are replaced by very expressive differences between countries and economic forces, which defend at all costs to maintain the environmental problems that currently occur.

Something has to be done urgently. However, one cannot expect that people individually can solve the problem of climate change, because the major causes for greenhouse gas emissions are not only the individuals. Governments need to intervene in an integrated and systematic way. But it seems that countries are waiting to see who will be the first to take steps in this direction. No nation is truly committed to tackling climate change without first checking if other competing countries will.

The restriction of pollutant emissions is often misunderstood because it’s seen as implying a decrease in industrial capacity and production of a country. But this is not true, if we observe that what is needed is to check the other alternatives and doing so to prevent recession or economic downturn.

Paragominas reached a stable social and economic level, even without degrading nature, and keeping their activities into new ecological standards. If it was possible there, it is possible globally. Undoubtedly it was possible using a tool often overlooked and discredited, called “public policy.”

Conclusions

National environmental laws, combined with effective and integrated public policies created by the dialogue between producers, investors, local power, and population, can effectively contribute to an improvement in climate change solutions.

International laws and treaties will only take effect if built on a structural transformation of industrial production and ways to maintain, or improve, economical context of the signatory countries, never forgetting that are indeed less polluting alternatives and viable solutions.

Paragominas managed to continue growing and producing wealth, however, without destroying and degrading the municipal area, preserving the environment and health of all citizens. This is possible globally, if there is the participation of companies and local governments, sharing good examples and building a more positive reality for all.

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Financing Adaptation to Climate Change in Developing Countries

Kanako Morita and Ken'ichi Matsumoto

Contents

Abstract

Adaptation assistance is a key element in promoting adaptation measures in developing countries. However, adaptation finance has not fully met the needs of adaptation in developing countries because of its limited amount and ineffective distribution. This chapter provides implications for designing more effective financing for adaptation under the United Nations Framework Convention on Climate Change, by analyzing the characteristics of two types of existing adaptation financing targeting Asia–Pacific developing countries: (1) multilateral adaptation funds related to the Global Environment Facility (GEF) and (2) bilateral

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official development assistance. The effects of the two financing schemes are compared, focusing on their financing rules and procedures and their targets and effects. The chapter shows that the adaptation finance schemes have strengths and weaknesses. The GEF-related multilateral adaptation finance has the potential to bring together various donors and organizations in implementing adaptation, while it has complex financing procedures and rules. Bilateral official development assistance is able to provide more adaptation finance, while it is more influenced by donors' interests. To promote adaptation activities effectively in developing countries, there is a need for an international framework for coordinating adaptation financing that enhances the strengths and minimizes the weaknesses of both financing systems.

Keywords
Financing • Adaptation • Global environment facility • Bilateral official development assistance • Asia–Pacific

Introduction

Climate governance involves the provision of financial resources to developing countries which are vulnerable to climate change. Assistance for adaptation to climate change is one of the key elements in promoting adaptation measures in developing countries. Developing countries are expected to be more affected by climate change than developed countries (IPCC 2007) because of geographical reasons and the lack of capabilities, financial resources, and technologies to implement adaptation measures. Further, climate change will ultimately threaten to prevent developing countries from achieving and sustaining their poverty reduction and development goals.

Under the United Nations Framework Convention on Climate Change (UNFCCC), developing countries have called for developed countries, which are primarily responsible for climate change, to assist their implementation of adaptation. The UNFCCC article 4, paragraph 4, calls for developed countries to assist developing countries "that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects," and financing for adaptation has been one of the key agendas in the UNFCCC negotiations on adaptation.

Three adaptation-related funds – the Special Climate Change Fund (SCCF), Least Developed Country Fund (LDCF), and Adaptation Fund – were established under the UNFCCC and the Kyoto Protocol, in the seventh session of the Conference of the Parties (COP) to the UNFCCC in 2007. In the sixteenth session of the COP in 2010, the Cancun Agreements were adopted; the agreements included US$30 billion in fast-start financing from developed countries to support both mitigation and adaptation in developing countries up to 2012, and the intention to raise a further US$100 billion per year by 2020. At the meeting, the parties also decided to establish the

Green Climate Fund, which aims to support developing countries by financing mitigation and adaptation projects, program policies, and activities (launched in the next COP meeting in 2011).

Further, developed countries have started to finance adaptation-related activities through official development assistance (ODA), and multiple aid agencies, international organizations, and nongovernmental organizations (NGOs) have started to assist adaptation in developing countries.

However, current adaptation finance has not fully met the needs of adaptation in developing countries. This is because of not only the lack of adaptation finance but also the lack of effectiveness of the distribution of adaptation finance.

This chapter presents implications for designing more effective financing for adaptation under the UNFCCC, by analyzing existing multilateral adaptation funds under the UNFCCC and the Kyoto Protocol and bilateral ODA for adaptation, targeting developing countries in the Asia–Pacific region.

Multilateral and Bilateral Finance for Adaptation

Although the estimates of costs of adaptation for developing countries are vague because of the complexity and variety of adaptations, all the estimates suggest the adaptation costs in developing countries will be in the ballpark of tens of billions of US dollars per year (UNDP 2007; UNFCCC 2007) or even higher, at US$70–100 billion per year (World Bank 2010).

Compared with the level of discussion on how to mobilize funds to achieve the adaptation needs of developing countries, there has been less discussion on the effective distribution of financing for adaptation. To mobilize finance for adaptation and to increase the willingness of donors to increase funds, it is necessary to show how funds are used. This chapter focuses on multilateral adaptation funds under the UNFCCC and the Kyoto Protocol, and bilateral ODA for adaptation outside the UNFCCC.

Multilateral Finance for Adaptation: Funds Related to the Global Environment Facility (GEF)

In the case of multilateral finance, this chapter focuses on GEF-related multilateral adaptation funds, which are the SCCF, LDCF under the UNFCCC, Adaptation Fund under the Kyoto Protocol, and GEF Trust Fund. The GEF operates the SCCF and LDCF, which are funded by voluntary contributions from individual countries. The GEF provides secretariat services to the Adaptation Fund Board on an interim basis, and the Adaptation Fund Board supervises and manages the Adaptation Fund (Decision 1/CMP.4 [decision adopted by the fourth session of the COP serving as the meeting of the Parties to the Kyoto protocol]).

(1) SCCF: Finances projects relating to adaptation; technology transfer and capacity building; energy, transport, industry, agriculture, forestry, and waste management; and economic diversification (UNFCCC Decision 7/CP.7). The SCCF has received approximately US$189 million as of October 1, 2012 (GEF/LDCF.SCCF.13/Inf.02).
(2) LDCF: Supports a work program to assist LDC Parties to carry out, inter alia, the preparation and implementation of national adaptation programs of actions (UNFCCC Decision 7/CP.7). The LDCF has received approximately US$370 million as of October 1, 2012 (GEF/LDCF.SCCF.13/Inf.02).
(3) Adaptation Fund: Finances concrete adaptation projects and programs in response to the Kyoto Protocol in developing countries that are particularly vulnerable to the adverse effects of climate change. It is financed by a share of proceeds of the Clean Development Mechanism (CDM) project activities and other sources of funding. The CDM allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol to implement an emission-reduction project in developing countries, and such projects can earn saleable Certified Emission Reduction credits, each equivalent to one ton of CO_2, which can be counted toward meeting Kyoto targets (UNFCCC 2013a). The share of proceeds amounts to 2 % of Certified Emission Reductions issued for a CDM project activity. The Adaptation Fund is supervised and managed by the Adaptation Fund Board, which comprises 16 members and 16 alternates and meets at least twice a year (UNFCCC 2013b). There is a strong mandate from the UNFCCC (LDCF and SCCF) and the Kyoto Protocol (Adaptation Fund) to keep these as distinct funds, and the Adaptation Fund is unique in its revenue regime, the composition of its governing body, and the "direct access" modality (the Adaptation Fund provides eligible developing countries direct access to the fund; GEF 2009). The Adaptation Fund has received approximately US$325 million as of March 31, 2013 (AFB/EFC.12/8).

GEF also operates its GEF Trust Fund, which has been the primary financial source of the GEF and also supports adaptation. The GEF, established in 1991, is the largest public funder of projects to improve the global environment (GEF 2013a), and the GEF provides grants in seven different areas: biodiversity; climate change; chemicals; international waters; land degradation; sustainable forest management/reducing emissions from deforestation and forest degradation in developing countries (REDD+), one of the climate change mitigation measures discussed under the UNFCCC; and ozone layer depletion. Additionally, the GEF supports cross-cutting issues and programs: results and learning of the projects, earth funds and public–private partnerships, capacity development, small-grant programs, country support programs, and gender mainstreaming (GEF 2013b). The GEF formally serves as a financial mechanism for the UNFCCC, Convention on Biological Diversity, Stockholm Convention on Persistent Organic Pollutants, and United Nations Convention to Combat Desertification and supports the implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer (although there is no formal link between the GEF and Montreal Protocol). The GEF is managed by 10 implementing agencies, namely, the

United Nations Environment Programme, United Nations Development Programme (UNDP), World Bank, Asian Development Bank, African Development Bank, European Bank for Reconstruction and Development, Food and Agriculture Organization of the United Nations, Inter-American Development Bank, International Fund for Agricultural Development, and United Nations Industrial Development Organization (GEF 2013c).

The GEF Trust Fund is replenished every 4 years. During the period of GEF 4 from 2006 to 2010, adaptation measures were supported by Strategic Priority on Adaptation (SPA) funding (US$50 million), which was provided by the GEF Trust Fund. The SPA was a groundbreaking initiative designed to support pilot and demonstration adaptation projects that provide real benefits and can be integrated into national policies and sustainable development planning (GEF 2013d). In GEF 5, from 2010 to 2015, adaptation-related works are financed through the LDCF and SCCF, and the GEF Trust Fund does not finance adaptation.

Bilateral Finance for Adaptation: Bilateral ODA

With regard to bilateral finance for adaptation, bilateral ODA outside the UNFCCC including European countries, Japan, and Australia has supported adaptation in developing countries. For example, so far, Japan, Germany, and Australia are the three largest bilateral donors financing adaptation in developing countries in the Asia–Pacific region. In 2010 and 2011, Japan financed US$2486 million, Germany US$480 million, and Australia US$318 million.

The Organisation for Economic Co-operation and Development (OECD), of which the developed countries mentioned above are members, has worked mainly on three areas on adaptation: (1) economic aspects of adaptation (providing guidance on a range of different economic policies and tools that countries will need to implement efficient adaptation), (2) adaptation and development (work to integrate effective adaptation into development activities for developing countries), and (3) adaptation in OECD countries (helping developed countries to ensure that key economic sectors and vulnerable groups are prepared for adaptation; OECD 2013a). The second area focuses on providing guidance for bilateral donors, by providing policy guidance to offer concrete information on how to facilitate the integration of adaptation within development processes (OECD 2009), providing an overview and assessment of tools for screening climate risks and integrating adaptation into development planning processes (Hammill and Tanner 2011), and providing the first empirical assessment of monitoring and evaluation frameworks used by development cooperation agencies and sharing lessons learned and common characteristics of monitoring and evaluation for adaptation (Lamhauge et al. 2012).

Unlike the case for GEF-related multilateral adaptation funds, it is difficult to track the process of adaptation finance from bilateral ODA. Atteridge et al. (2009) calculated the amount of annual adaptation finance (as ODA) of Agence Française de Développement, the Japan International Cooperation Agency (JICA), and the German Development Bank in 2008, but there were no comprehensive data on adaptation finance of bilateral ODAs. In December 2009, the OECD Development Assistance Committee (DAC) members approved a new marker to track aid in support of adaptation, which complements the existing climate change mitigation marker and allows the presentation of a more complete picture of aid in support of developing countries' efforts to address climate change (OECD 2013b). Data have been obtained using the adaptation marker since 2010. In 2011, DAC members also agreed to extend the application of the mitigation and adaptation markers to non-concessional development loans (OECD 2012). According to the OECD data, OECD countries provided approximately US$16795 million in the form of bilateral ODA to assist adaptation in developing countries in 2010 and 2011 (OECD Creditor Reporting System database, see p. 5).

Research Approach

In adaptation research, financing for adaptation has begun to receive more attention (Klein et al. 2007; Möhner and Klein 2007; Barr et al. 2010). However, much discussion and research have focused on how to mobilize adequate funds to promote adaptation in developing countries (Müller 2008; Persson 2011; Eisenack 2012), and there has been less discussion regarding effective and efficient ways to distribute these funds (Barr et al. 2010; Fankhauser and Burton 2011). There has not been much progress toward the design of effective and efficient financing for adaptation in developing countries.

This chapter analyzes the characteristics of existing multilateral and bilateral adaptation financing for developing countries in the Asia–Pacific region, by focusing on how the financing is allocated to these countries, which is an important element in examining the effectiveness of the financing. As mentioned above, this study focuses on two types of funding sources: (1) GEF-related multilateral funds for adaptation, namely, the SCCF, LDCF, Adaptation Fund, and GEF Trust Fund and (2) bilateral ODA adaptation finance. The effects of the two financing systems are compared, focusing on their differences and similarities in how finances for adaptation are distributed and the institutional barriers to finance for adaptation. To be more specific, this study analyzes (1) adaptation financing rules and procedures and (2) adaptation financing targets and effects (i.e., characteristics of adaptation distributions by country and sector). With regard to the GEF-related multilateral adaptation funds, this study especially focuses on the SCCF and LDCF as these are the two major adaptation-related funds that the GEF is currently managing.

This research uses not only the qualitative data from related reports published by donors and NGOs and academic papers but also quantitative data from databases mainly constructed by the GEF, OECD, and Climate Funds Update, as described below.

(1) GEF Project Database (GEF 2013e): The GEF provides information on projects that are funded by the GEF Trust Fund, and also the SCCF and LDCF. Also, adaptation project data received from GEF officers are used (GEF 2013f, g).

(2) OECD Creditor Reporting System (CRS) database (OECD 2013c): Unlike the DAC annual aggregates database, which provides comprehensive data on the volume, origin, and types of aid and other resource flows, the CRS provides detailed information on individual aid activities, such as information on sectors, countries, and project descriptions. As stated above, in 2010, an adaptation marker was added to the CRS database, and adaptation data have been collected since 2010 using the marker.

(3) Climate Funds Update (Climate Funds Update 2013): This database is a joint initiative of the Heinrich Böll Stiftung and the Overseas Development Institute. Climate Funds Update tracks all multilaterally governed funds focused on climate change and major bilateral initiatives. The database focuses on the funding of adaptation, mitigation, and REDD+.

This study focuses on developing countries in the Asia–Pacific region, which include Bangladesh, Bhutan, Cambodia, China, Cook Islands, Fiji, India, Indonesia, Kiribati, Lao PDR, Malaysia, Maldives, Marshall Islands, Mongolia, Myanmar, Nepal, North Korea, Pakistan, Palau, Papua New Guinea, the Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, Vietnam, Micronesia (Federated States of), Nauru, Niue, Tokelau, and Wallis and Futuna. The countries include small-island developing states (SIDS) and LDCs that are particularly vulnerable to climate change. SIDS in Asia Pacific include Fiji, Kiribati, Micronesia (Federated States of), Nauru, Palau, Papua New Guinea, Samoa, Singapore, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Vanuatu, Cook Islands, and Niue. LDCs in Asia Pacific include Bangladesh, Bhutan, Cambodia, Kiribati, Lao PDR, Myanmar, Nepal, Samoa, Solomon Islands, Timor-Leste, Tuvalu, and Vanuatu.

Adaptation measures involve multiple sectors. This study uses the following categories of adaptation: water (water supply and sanitation), natural resource management (biosphere and biodiversity protection), agriculture (agriculture, forestry, fishing, and food), infrastructure (social infrastructure and services, transport, communication, energy, industry, mining, construction, tourism, and education), human health (health and population), disaster risk management and coastal zone management (reconstruction relief and rehabilitation, disaster prevention and preparedness, and emergency response), and others (climate information services, etc.).

Characteristics of Multilateral and Bilateral Adaptation Finance

Institutional Strengths and Challenges in Implementing the Rules and Procedures for Adaptation Financing

GEF-Related Multilateral Adaption Finance

As mentioned above, the SCCF, LDCF, and GEF Trust Fund are all managed by the GEF, and the GEF also provides secretariat services to the Adaptation Fund Board on an interim basis. This section mainly focuses on the SCCF and LDCF rules and

Table 1 Processes and key concepts in preparation for project implementation in the SCCF and LDCF project cycle

	SCCF	LDCF
Funding request	The SCCF project proponent develops a concept for a project and requests assistance from an Implementing Agency of the GEF	The LDCF project proponent develops a concept for a project and requests assistance from an Implementing Agency of the GEF
Endorsement	The SCCF project proponent secures the endorsement of the national GEF Operational Focal Point	The LDCF project proponent secures the endorsement of the national GEF Operational Focal Point
Project type	Projects over US$1 million are referred to as full-sized projects (FSPs); those of US$1 million or below are referred to as medium-sized projects (MSPs). MSPs, compared with FSPs, follow a further streamlined project cycle	Projects over US$2 million are referred to as FSPs; those of US$2 million or below are referred to as MSPs. MSPs, compared with FSPs, follow a further streamlined project cycle
FSPs	For FSPs, submission to the GEF under the SCCF starts with a Project Identification Form (approved by the LDCF/SCCF Council), followed by a CEO Endorsement Form	For FSPs, submission to the GEF under the LDCF starts with a Project Identification Form (approved by the LDCF/SCCF Council), followed by a CEO Endorsement Form
MSPs	MSPs may start with the CEO Endorsement Form. Once the GEF CEO endorses the project, the funding is released to the implementing agency	MSPs may start with the CEO Endorsement Form. Once the GEF CEO endorses the project, the funding is released to the implementing agency

Source: GEF 2011a, b

procedures. Table 1 shows the processes and key concepts in preparation for project implementation in the SCCF and LDCF project cycle. The project cycle for the SCCF is similar to that employed by the GEF Trust Fund, while that for the LDCF is more streamlined than that employed by the GEF Trust Fund. Each of the stages of the project cycle is approved by the LDCF/SCCF Council and/or GEF chief executive officer (CEO). The GEF Agency works closely with the country at each successive step and ultimately assists the country in implementing the project (GEF 2011a, b).

Following the CEO endorsement of the project, the SCCF and LDCF funding is ready to be released to the country through the implementing agency, and the project can begin implementation. The implementing agency is responsible for preparing specific reports during certain stages of the project, and the agency is required, for example, to submit project implementation reports on an annual basis and to submit a terminal evaluation to the GEF Evaluation Office within 12 months of the operational completion of a project (GEF 2011a, b). To measure the progress and results of the project, the GEF secretariat and its agencies have developed a Results-Based Management Framework. The work plans of the Results-Based Management in GEF 5 include establishing and implementing an updated Annual Monitoring Review process for GEF 5, upgrading and integrating portfolio monitoring in the Project Management Information System, and developing tools to enhance portfolio monitoring (GEF/C.39/6/Rev.1). Furthermore, to assist the tracking of project-specific outcomes and output indicators, which are reported in the annual Project Identification Form, the LDCF/SCCF Adaptation Monitoring and Assessment Tool has been devised (GEF 2011a, b, 2013h).

The strength of the GEF in financing adaptation is that it operates funds in close connection with the UNFCCC. The UNFCCC requests that the GEF finances adaptation in developing countries. Additionally, since the financial mechanism of the GEF involves several implementing agencies, and co-funding agencies, the GEF is able to bring together various donors and organizations in implementing adaptation. The former CEO and Chairperson of the GEF, Monique Barbut, stated that the GEF is important in financing adaptation. She listed the general strengths of the GEF as follows:

> The GEF is a financial mechanism under the United Nations conventions. Unlike other aid agencies, the GEF receives guidance from the conventions. The GEF has institutional links with the United Nations conventions and United Nations systems. The legitimacy of the GEF is different from any other aid agencies. The GEF is able to fund the projects which produce the global environmental benefits. The GEF is able to support the environmental projects which have technical and institutional risks. GEF funding is based on grants. When an agency agrees to a loan, it has to be sure that the loan will be repaid and it thus has to ensure that only confirmed technologies are being used, so as to avoid large risks in the project. However, the GEF has not been built on this logic. The GEF is supposed to test new technologies in pilot projects and to be innovative, and it is able to do this because most of the GEF's assistance is from grants. (Interview with Monique Barbut, the CEO and Chairperson of the GEF, 23 May 2009). Other aid agencies only take little technical and institutional risks of the environmental projects. (Interview with Monique Barbut, 23 May 2009)

As for the strengths of the GEF in funding adaptation, she stated:

> The GEF is able to play a central role in coordinating a variety of people in different aid agencies and organizations. The GEF is only a funding mechanism and does not have enough money itself. However, the GEF is able to bring together the various donors and organizations to implement climate change adaptation projects, and is able to be a central part of the climate change adaptation financing. (While, for example, if the money is put to other aid agencies like the UNDP, the money will be used only for the UNDP projects.) The UNFCCC asks guidance and strictly review reports on climate change adaptation to the GEF. (Interview with Monique Barbut, 23 May 2009)

In this way, the GEF has general strengths in financing adaptation in terms of having strong links with the UNFCCC, receiving guidance from the UNFCCC COP, and involving multiple donors and organizations in the financing process. Additionally, since the GEF financing is based on grants that recipients do not need to repay, the GEF can take risks in implementing new pilot adaptation projects (Interview with Monique Barbut, 23 May 2009).

However, the general challenges facing GEF-related funds are as follows. First is that the GEF's governance structures are seen by developing countries as complex and weighted in favor of donor countries, and the rules and structures make accessing funding difficult and time-consuming (Mitchell et al. 2008). Second, there is a lack of transparency in decision making that appears to be the prerogative of powerful individuals (Mitchell et al. 2008). Compared with the one-country-one-vote voting procedure of the Adaptation Fund under the Kyoto Protocol, the GEF is subject to the traditional and, according to developing countries, far less democratic GEF voting procedure that requires a majority of both countries and donations to carry a vote (Grasso 2011, p. 364). This has been made evident by the negotiation processes of the Adaptation Fund; developing countries constantly demanded their inclusion in the governance structures of the Adaptation Fund and strenuously rejected the GEF as the financial entity to manage it, owing to their scant participation in the GEF governance system (Grasso 2010, p. 146). Thirdly, there is a fundamental concern about the low level and the lack of predictability of funding provided through the LDCF and SCCF (GEF NGO Network Statement on GEF Programming Strategy paper for Adaptation to Climate Change under the LDCF and SCCF [GEF Meeting on Financing for LDCF and SCCF, 4 April 2013]).

With regard to the complex and time-consuming processes, although funding through the GEF is not formally conditional, requirements attached to funding include burdensome reporting and co-financing criteria (Ayers and Huq 2008). For example, the LDCF and SCCF, addressing the adverse impacts of climate change, impose additional costs on vulnerable countries striving to achieve their development goals. The LDCF and SCCF finance the "additional costs" imposed on vulnerable countries to meet their adaptation needs due to the adverse impacts of climate change, while the costs associated with baseline development activities must be supported by co-financiers (Ayers and Huq 2008; GEF 2009).

Although the GEF Trust Fund is not used for financing adaptation in GEF 5, unlike the SCCF and LDCF, the GEF Trust Fund needs to act according to GEF principles. The two main principles of the GEF, regarding "global environmental benefits" and "incremental costs," particularly limit the implementation of adaptation projects. Concerning global environmental benefits, mitigation activities, which aim at reducing atmospheric greenhouse gas concentrations, clearly have global benefits; however, for adaptation activities, it is difficult to imagine how global benefits can be gained, for adaptation mostly takes place at the local level (Klein 2002). The SCCF and LDCF under the UNFCCC must follow the decision of the COP, and "additional costs," which SCCF and LDCF finance, cover the full cost of adaptation if the developing country already has resources for its basic development program. Conversely, the GEF Trust Fund's "incremental costs" associated with transforming a project with national benefits into one with global environmental benefits are more difficult to identify.

Table 2 shows the major distinctions between the GEF Trust Fund and SCCF/LDCF.

Bilateral ODA Finance for Adaptation

Bilateral ODA mainly supports adaptation in developing countries through mainstreaming adaptation into traditional ODA. Mainstreaming involves the integration of policies and measures that address climate change within development planning and ongoing sectoral decision making so as to ensure the long-term sustainability of investments and to reduce the sensitivity of development activities

Table 2 Distinctions between the GEF Trust Fund and SCCF/LDCF

	Conventional GEF Trust Fund	SCCF	LDCF
Project must have global benefits	Yes	No	No
Projects must have adaptation benefits	No	Yes	Yes
Funding allocated according to the Resource Allocation Framework or STAR[a]	Yes	No	No
Projects financed according to the "incremental costs" principle	Yes	No	No

Created from GEF (2011a, b)
[a]The recently denominated STAR has been developed for climate change mitigation (GEF 2009)

to both the current and future climates (Klein et al. 2007). OECD members agreed on the Declaration on Integrating Climate Change Adaptation into Development Co-operation at the meeting of the OECD DAC and the Environment Policy Committee at the ministerial level in 2006. Additionally, the Statement of Progress on Integrating Climate Change Adaptation into Development Co-operation was adopted at the 2008 DAC High-Level Meeting. As mentioned above, the OECD has worked on adaptation and development (work to integrate effective adaptation into development activities for developing countries) as one of its three main areas. The OECD has, for example, provided policy guidance to bilateral donors to help facilitate the integration of adaptation within development processes (OECD 2009) and provided an overview and assessment of tools for screening climate risks and integrating adaptation into development planning processes (Hammill and Tanner 2011). Further, the application of the adaptation marker to data beginning in 2010 has allowed the tracking of adaptation finance through bilateral ODA.

Although the OECD provides general policy guidance for integrating adaptation in development processes, each bilateral aid agency establishes its adaptation support strategy for developing countries. Japan is the largest bilateral ODA adaptation funder for developing countries in the Asia–Pacific region. Figure 1 shows the general environmental ODA from Japan to developing countries.

The JICA published the report *JICA's Assistance for Adaptation to Climate Change* (JICA 2007) and presented the JICA's possible cooperation for adaptation by sector, and the JICA's approaches to adaptation. Further, the report showed how existing development projects had potential effects on adaptation. Since then, the JICA has supported projects that will enhance adaptation effects. In 2011, the JICA published *JICA Climate Finance Impact Tool for Adaptation* (JICA 2011), which is a reference document that discusses issues in mainstreaming adaptation during the planning stages of country assistance strategies and individual projects by summarizing them as concepts and guidelines. Figure 2 shows the formulation processes for adaptation projects and business-as-usual development with adaptation options.

Each bilateral aid agency has its own strategy and focus. With regard to Germany, the German Technical Cooperation (GTZ), which is now part of the German Society for International Cooperation (GIZ), has worked on mainstreaming adaptation. The GTZ (GIZ) published a manual for practitioners, *Climate Change*

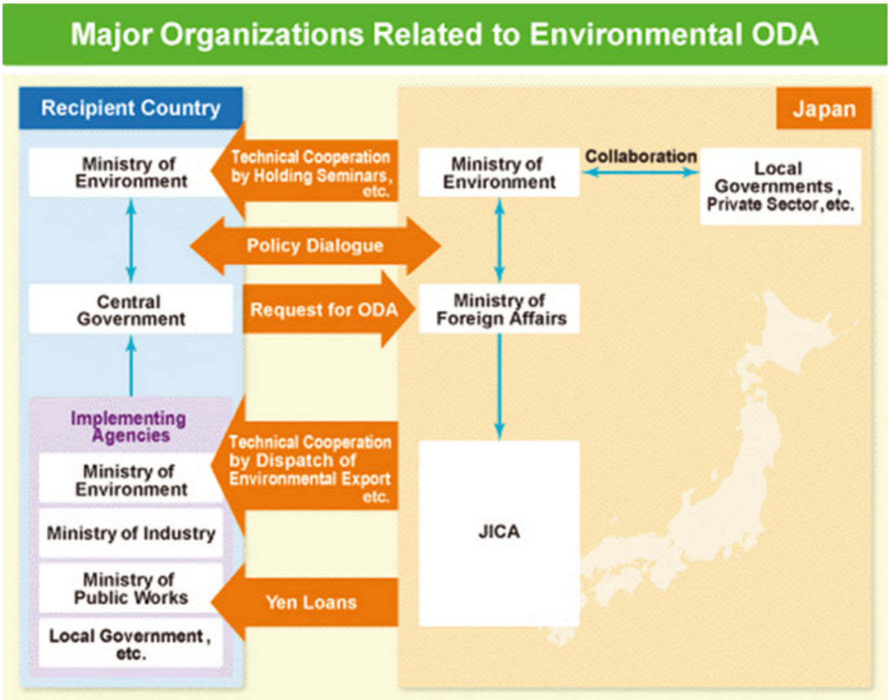

Fig. 1 Japanese environmental ODA (Source: Ministry of the Environment of Japan (2013))

Information for Effective Adaptation, which aims to enhance the capacity of those practitioners and decision makers in developing countries by translating relevant aspects of climate change research into their everyday working contexts, by describing the concrete steps of (1) how to obtain climate change information, (2) how to interpret it adequately, and (3) how to communicate the resulting knowledge in a careful and responsible way (Kropp and Scholze 2009). Further, the GIZ has developed a Climate Proofing for Development method. Applying Climate Proofing for Development at the scale of an entire country is a very efficient means of mainstreaming the issue of adaptation in national agendas and budgetary decisions (Hahn and Fröde 2011).

Bilateral ODA could use financial and human resources effectively and efficiently by mainstreaming adaptation into the development process, rather than by designing, implementing, and managing climate policy separately from ongoing activities (Klein et al. 2007). As mentioned above, several bilateral aid agencies such as the JICA and GIZ have started to integrate adaptation into their ODA activities. In this way, by mainstreaming adaptation into bilateral ODA activities, the recipients are able to make good use of bilateral aid agencies' experience and skills that have been acquired from previous development projects involving adaptation-related activities. Additionally, unlike the case for GEF-related financing, bilateral aid agencies can provide the full costs of projects, as they do not require co-funding from other donors. This makes it easier for developing countries (which have difficulty finding co-funders) to implement projects. Furthermore, bilateral aid agencies finance projects not only through grants but also by loans. Developing countries that have a relatively strong economic basis can thus implement large-scale projects funded by loans. In addition to the abovementioned benefits, when the interests of bilateral aid agencies match the needs of developing countries, the developing countries can more easily receive funds from bilateral aid agencies than from multilateral aid agencies.

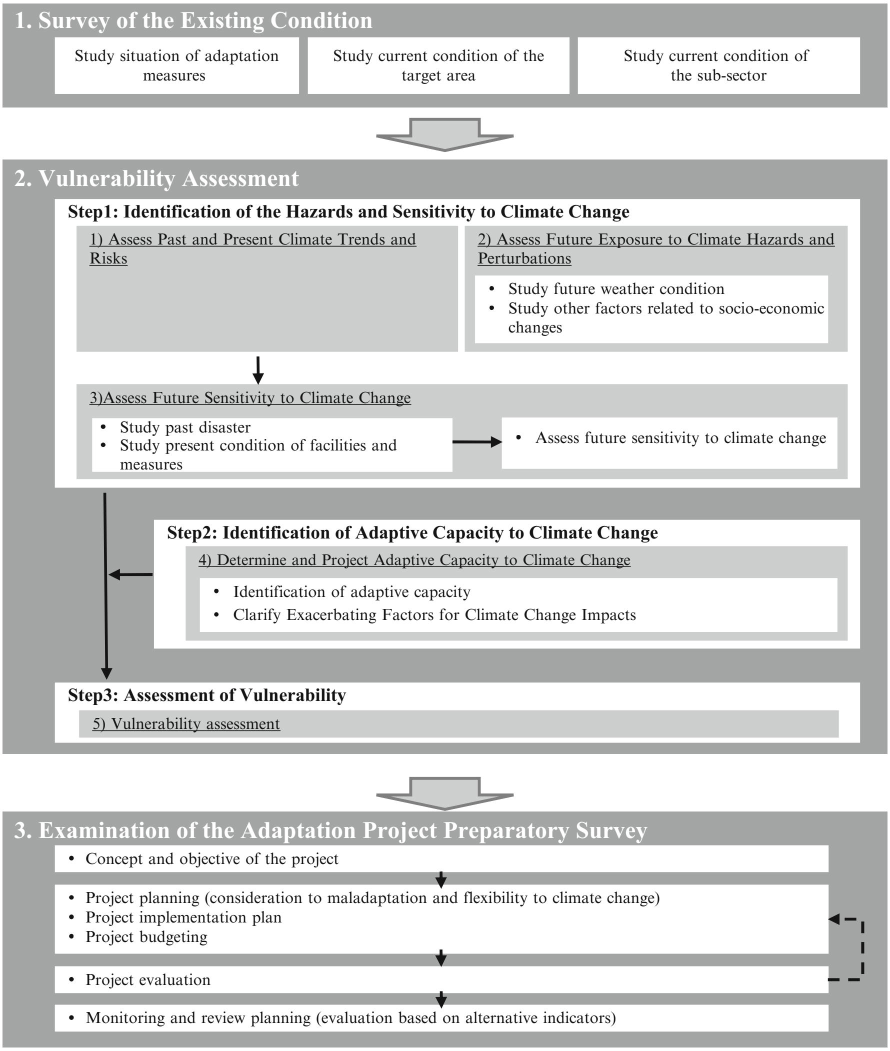

Fig. 2 (continued)

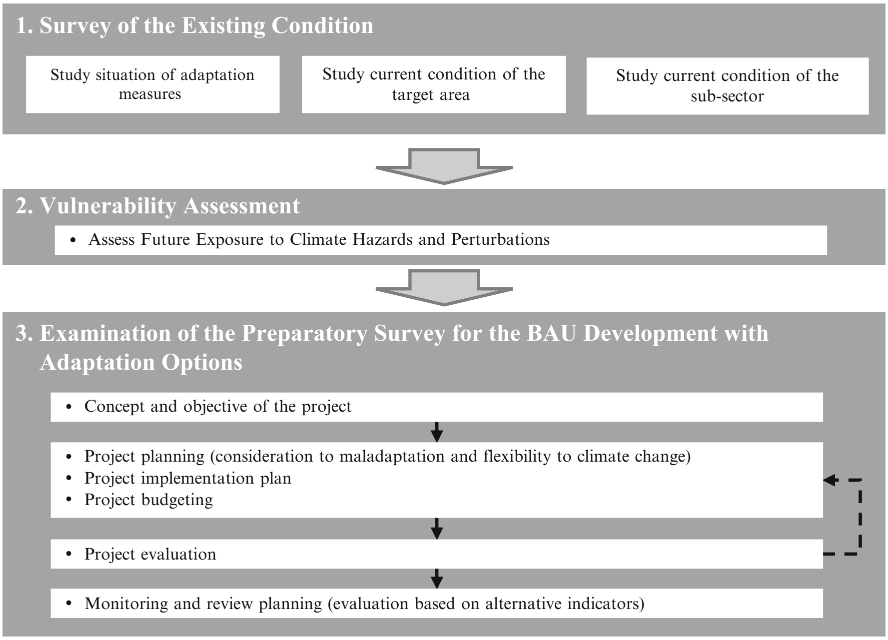

Fig. 2 Formulation processes for an adaptation project and business-as-usual development with adaptation options (Source: JICA (2011))

However, in general, the bilateral development assistance is one of the tools at the disposal of developed country governments as an element of their foreign policies and is usually aligned with their strategic objectives and interests, and the mix of aid motivations varies from one donor country to another and also over time (Sagasti et al. 2005, p. 69). Sagasti et al. (2005) described that there appear to be three main sets of rationales for development assistance: international solidarity and religious motivations, narrow and enlightened self-interest, and the provision of international public goods. For example, in general, Japan allocates more aid to its neighbors in East and Southeast Asia, which are also its main trade partners and the principal destinations of its foreign investments (IBON International 2009).

As described, when the interests of bilateral aid agencies match the adaptation needs of developing countries, it is likely that the developing countries will be more easily able to receive funds for adaptation from bilateral aid agencies than from multilateral aid agencies. However, since bilateral aid is generally more influenced by donor interests as compared with multilateral aid, when the interests of bilateral aid agencies do not match developing countries' adaptation needs, developing countries will have difficulty receiving sufficient funds. Furthermore, another controversial point in funding adaptation through bilateral ODA is the additionality to existing ODA commitments (i.e., ODA contributions at 0.7 % of gross national income). There are concerns that the use of existing funds such as ODA for adaptation could take the pressure off donors to provide additional resources (Yamin 2004) and that ODA-related adaptation activities are diverted from ODA commitments (Oxfam 2007).

Adaptation Financing Targets and Effects

The previous section compared the characteristics of two types of adaptation financing according to their rules and procedures. This section describes how these adaptation finances are actually distributed to adaptation in developing countries in the Asia–Pacific region quantitatively. As mentioned above, this study analyzes the allocation of adaptation finance using the data from the OECD CRS, GEF, and Climate Funds Update databases. Further, to examine the characteristics of distribution of adaptation finance to developing countries in the Asia–Pacific region, this research uses the accumulated amount of finance. This is because aid agencies usually provide finance to adaptation programs and projects that are implemented for several years, and the amount of finance in only a specific year does not present fairly the trends of distribution of adaptation finance. As for GEF-related multilateral adaptation funds, the total accumulated amount of finance is used. With regard to bilateral ODA, since the OECD has introduced an adaptation marker for data from 2010 onwards, the accumulated amount of finance for 2010 and 2011 is used.

Allocation of Adaptation Finance to Developing Countries in the Asia–Pacific Region

Financial support for adaptation contributed to developing countries in the Asia–Pacific region through multilateral funds is so far limited. As described in Table 3, GEF-related multilateral adaptation funds (accumulated) are much less than the accumulated amount of adaptation finance from bilateral ODA to developing countries in the Asia–Pacific region (total for 2010 and 2011). Further, although

Table 3 Adaptation finance for developing countries in the Asia–Pacific region (US$ million)[a]

GEF-related multilateral adaptation funds (accumulated)	Bilateral ODA adaptation finance of five major countries and the total (2010 and 2011)
SCCF: 75	Japan: 2486
LDCF: 181	Germany: 480
Adaptation Fund: 78	Australia: 318
GEF Trust Fund: 20	EU institutions: 243
	Korea: 202
Total: 354	Total: 4771

Data source: Climate Funds Update, OECD CRS, and GEF databases (detailed GEF data received from the GEF on June 5, 2013)

[a]The amount of GEF-related multilateral adaptation funds is approved and distributed dataThe amount of bilateral ODA adaptation finance reflects current prices

bilateral ODA provides more adaptation finance than GEF-related multilateral adaptation funds, the average share of adaptation financing to the total climate change finance in the Asia–Pacific region (total for 2010 and 2011) is only 29.8 %. This shows that the bilateral ODA has more interest in financing mitigation than adaptation.

Allocation of Adaptation Finance to Different Countries in the Asia–Pacific Region

Next, this study focuses on how the adaptation finance is distributed to each developing country in the Asia–Pacific region. Figure 3 shows the amount of finance that developing countries in the Asia–Pacific received from the four GEF-related multilateral adaptation funds. Table 4 shows the finance received from each GEF-related multilateral adaptation fund.

Note that “Regional” in Figure 3 and Table 4 is finance contributed to regional projects. The countries included in Regional 1 are the Cook Islands, Fiji, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu; Regional 2 comprises the Cook Islands, Fiji, Kiribati, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu; Regional 3 comprises Asia and the Pacific; and Regional 4 comprises Cambodia, China, Lao PDR, Myanmar, Thailand, and Vietnam. The same regions are used in Table 4.

Figure 4 shows the amount of adaptation finance that developing countries in the Asia–Pacific region received from all bilateral ODA. Table 5 presents the finance

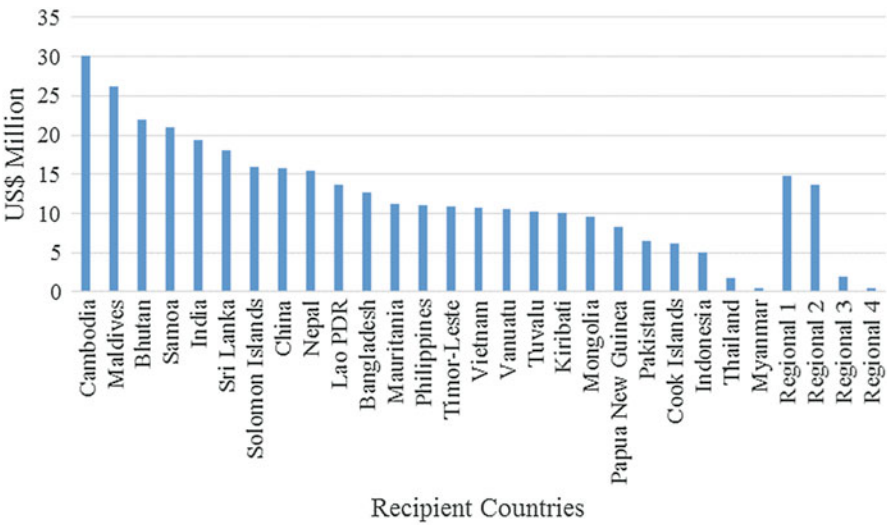

Fig. 3 Allocation of adaptation finance from four GEF-related multilateral adaptation funds to the Asia–Pacific region (Data source: Climate Funds Update database)

Table 4 Allocation of adaptation finance from the SCCF, LDCF, Adaptation Fund, and GEF Trust Fund to the Asia–Pacific region (million US$)

	SCCF		LDCF		Adaptation Fund		GEF Trust Fund (GEF4) – SPA	
1	China	15.8	Cambodia	24.0	Maldives	14.4	India	9.6
2	Regional 1	14.8	Bhutan	22.0	Sri Lanka	10.8	Sri Lanka	4.2
3	Philippines	11.0	Nepal	15.5	Samoa	10.2	Kiribati	4.1
4	Vietnam	10.7	Regional 2	13.7	Solomon Islands	8.6	Regional 3	2
5	India	9.8	Lao PDR	13.6	Papua New Guinea	8.3		
6	Indonesia	5.0	Bangladesh	12.7	Pakistan	6.5		
7	Sri Lanka	3.1	Maldives	11.8	Mongolia	6.5		
8	Mongolia	3.0	Timor-Leste	10.9	Cook Islands	6.2		
9	Thailand	1.7	Samoa	10.8	Cambodia	6.1		
10	Regional 4	0.5	Vanuatu	10.6				

Data source: Climate Funds Updates

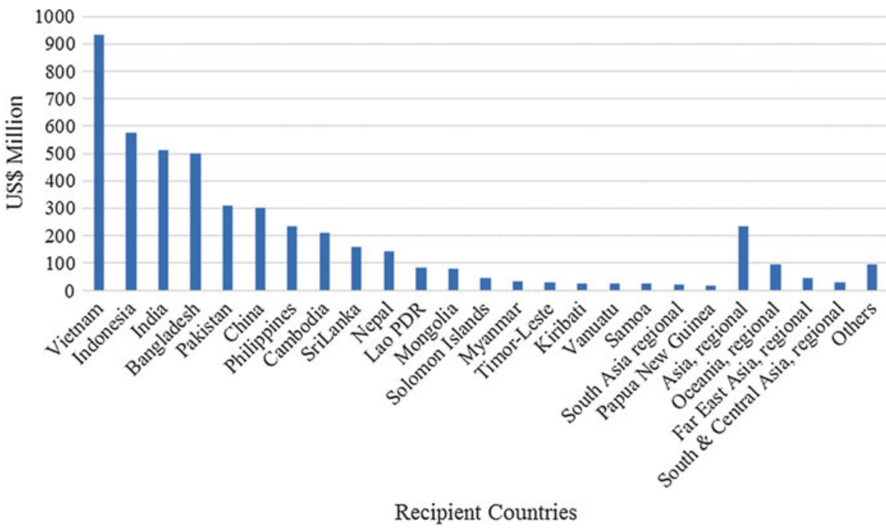

Fig. 4 Allocation of adaptation finance from bilateral ODA to the Asia–Pacific region (Data source: OECD CRS database)

that developing countries in the Asia–Pacific region received from three of the largest bilateral ODA funders (i.e., Japan, Germany, and Australia).

Note that "regional" includes finance to regional projects and initiatives. "Asia regional" comprises Far East Asia, South and Central Asia, and the Middle East.

Table 5 Allocation of adaptation finance from Japan, Germany, and Australia to the Asia–Pacific region (US$ million)

	Japan		Germany		Australia	
1	Vietnam	679.6	China	181.6	Oceania, regional	56.3
2	India	402.4	Vietnam	53.8	Solomon Islands	34.1
3	Indonesia	357.3	India	43.3	Indonesia	27.9
4	Pakistan	257.6	Bangladesh	40.4	Kiribati	21.9
5	Bangladesh	215.3	Lao PDR	32.5	Papua New Guinea	19.5
6	Cambodia	149.4	Asia, regional	22.8	Asia, regional	18.5
7	Sri Lanka	145.7	Philippines	22.7	Philippines	15.8
8	Philippines	144.3	Cambodia	17.2	Timor-Leste	14.8
9	Mongolia	41.6	Nepal	17.1	Vanuatu	14.2
10	Lao PDR	19.4	Far East Asia, regional	13.8	Vietnam	11.1

Data source: OECD CRS database

"Far East Asia regional" comprises Cambodia, China, Indonesia, Lao PDR, Malaysia, Mongolia, North Korea, the Philippines, Thailand, Timor-Leste, and Vietnam; "South and Central Asia regional" comprises Afghanistan, Armenia, Azerbaijan, Bangladesh, Bhutan, Georgia, India, Kazakhstan, the Kyrgyz Republic, Maldives, Myanmar, Nepal, Pakistan, Sri Lanka, Tajikistan, Turkmenistan, and Uzbekistan; "Oceania regional" comprises the Cook Islands, Fiji, Kiribati, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, and Wallis and Futuna. As the countries in the Central Asia and Middle East are outside the scope of this research, the data of finance to each country in these areas is not included.

Comparing GEF-related multilateral adaptation funds with bilateral ODA adaptation finance, GEF-related multilateral adaptation funds in general support adaptation in developing countries of the Asia–Pacific region more broadly in terms of having fewer gaps in financing among developing countries including SIDS and LDCs. However, bilateral ODA adaptation finance focuses on emerging countries such as Vietnam, Indonesia, and India. However, there are differences in the characteristics of adaptation finance among GEF-related multilateral adaptation funds and among bilateral ODA adaptation finance. As for GEF-related multilateral adaptation funds, compared with the SCCF and LDCF, which finance a wide range of developing countries and regional projects, the Adaptation Fund and GEF Trust Fund finance only a limited range of countries. With regard to bilateral ODA adaptation finance, Japan has intensively financed Vietnam (followed by India and Indonesia), while Germany intensively finances China (followed by Vietnam and India) in the Asia–Pacific region. Unlike Japan and Germany, which intensively finance adaptation in emerging countries, Australia intensively finances adaptation in the Oceania region including SIDS and LDCs, because the primary geographic emphasis of its adaptation program is on Australia's neighboring island countries (Australian Agency for International Development 2013).

Allocation of Adaptation Finance to Different Sectors in the Asia–Pacific Region

Figures 5 and 6 show that the financing targets of GEF-related multilateral adaptation funds and bilateral ODA adaptation finance differ. The former focuses on financing adaptation in disaster risk and coastal zone management sectors, while the

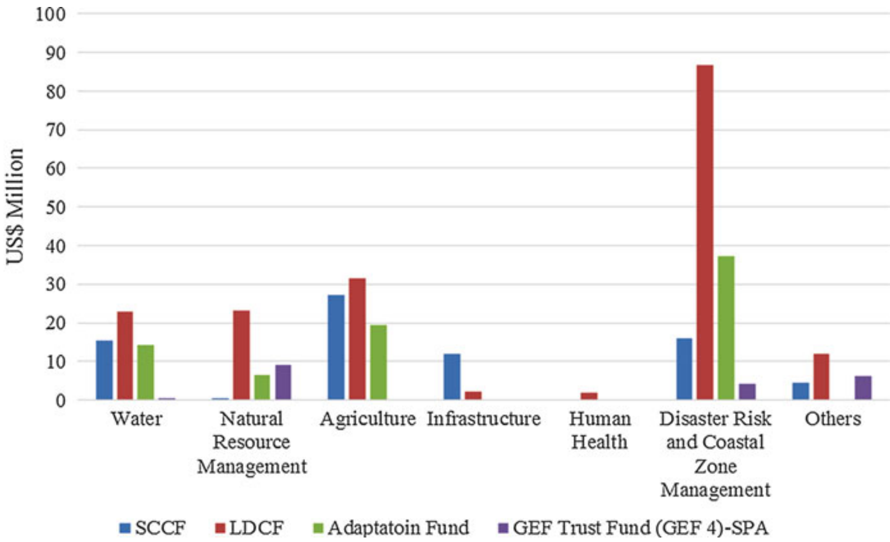

Fig. 5 Allocation of GEF-related multilateral adaptation funds to sectors in the Asia–Pacific region (Data source: Climate Funds Update and GEF databases)

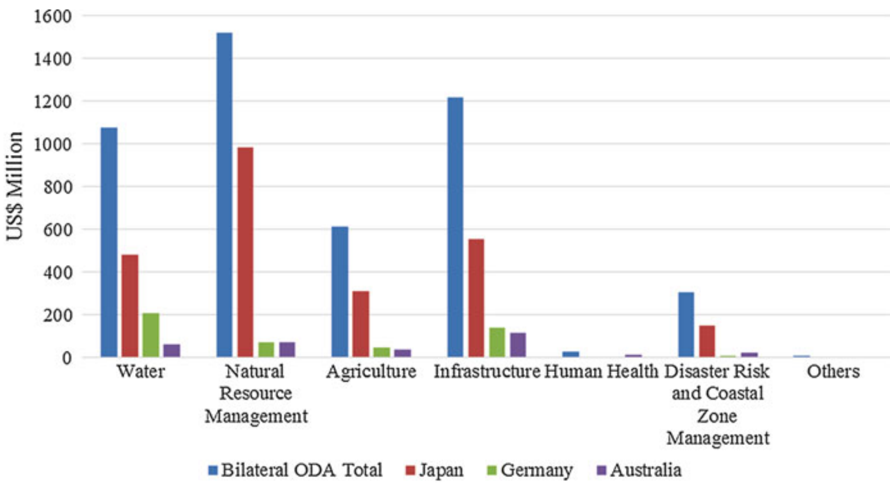

Fig. 6 Allocation of bilateral ODA adaptation finance to sectors in the Asia–Pacific region (Data source: OECD CRS database)

latter focuses on financing natural resource management, water, and infrastructure sectors. The differences in the main targeted sectors of the two types of financing probably arise from the differences in the adaptation needs of the main targeted developing countries in the Asia–Pacific region. Roughly, GEF-related multilateral adaptation funds mainly finance SIDS and LDCs in the Asia–Pacific region, which require adaptation in terms of disaster risk and coastal zone management, while bilateral ODA adaptation finance is mainly used by emerging countries that are likely to require assistance in natural resource management, water, and infrastructure sectors. Neither fund well finances adaptation in the human health sector.

Concluding Remarks: Creating an Effective Institutional Framework for Financing Adaptation

This chapter presented the characteristics of GEF-related multilateral adaptation funds and bilateral ODA adaptation finance, especially focusing on the distribution of adaptation finance to developing countries in the Asia–Pacific region. Finance for adaptation is one of the key elements of climate change governance.

By analyzing the rules and procedures and the financing distributions of the two types of adaptation financing, this study showed that both multilateral and bilateral methods of financing adaptation have various strengths and challenges, and different characteristics, and showed the importance of enhancing their strengths. For example, GEF-related multilateral adaptation funds are controlled in close connection with the UNFCCC. The GEF is able to bring together various donors and organizations in implementing adaptation projects and programs and also to comprehensively finance SIDS and LDCs in the Asia–Pacific region. Additionally, the funds are particular focused toward financing adaptation measures in the sectors of disaster risk management and coastal zone management in the area. However, the complex financing procedures and rules pose challenges to the effective implementation of GEF-related funds; the funds usually go toward additional costs or incremental costs of adaptation programs and projects and are limited compared with bilateral ODA adaptation finance.

Conversely, this analysis showed that bilateral ODA adaptation finance is larger and able to meet the full cost of adaptation projects. However, bilateral ODA is more influenced by donors' interests, and the bilateral aid agencies tend to focus on financing adaptation in emerging countries in the Asia–Pacific region. Additionally, each donor has different strategies in terms of their financing targets: countries and sectors. Bilateral ODA tends to finance more adaptation in the sectors of natural resource management, infrastructure, and water in the Asia–Pacific region, compared with GEF-related multilateral adaptation funds.

To promote adaptation activities effectively in developing countries in the Asia–Pacific region, this research shows that it is important to enhance the strengths of each financing scheme. In doing so, it is necessary to construct an international framework for coordinating adaptation financing. The Green Climate Fund, which was launched at the UNFCCC COP meeting in 2011, will finance both mitigation and adaptation actions in developing countries. To make effective use of the existing funds and new Green Climate Funds for adaptation, it is necessary to establish common rules and criteria to identify the needs of adaptation in developing countries and to monitor and evaluate the adaptation activities.

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Financing Climate Adaptation and Mitigation in India

Dhanapal Govindarajulu

Contents

Abstract

India is among the developing countries that are vulnerable to climate change, while also in need to promote economic growth to alleviate poverty. To promote sustainable, low-carbon, and climate-resilient growth, India will require continuous efforts in mitigation and adaptation through Nationally Appropriate Mitigation Actions and National and State Adaptation Plans. This chapter analyzes the financial requirements for mitigation and adaptation in India and highlights that

Note: All financial estimates of Government of India in Indian Rupee were converted to US$ at the most prevailed rate of 2014, 1US$ = 60 INR

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multilateral agencies' support in climate mitigation and adaptation has been higher in the past than the funds received through global funds established through climate change conventions. The chapter recommends that though continuous support of multilateral agencies will be required in the future, efforts to access mitigation and adaptation funds must be made through global climate change negotiations.

Keywords
India • Climate finance • Mitigation • Adaptation

Introduction

Dash et al. (2007), Goswami et al. (2006) showed considerable evidence of a changing climate in India, on increase in sea surface and land temperature and changes in rainfall pattern. The Indian Network for Climate Change Adaptation (INCCA 2010) report based on PRECIS model results (Kumar et al. 2006) predicts an average temperature rise of 2.0° centigrade in India with 1.0–4.0° centigrade at extreme ranges by 2050. The model also predicts increased annual precipitation, lower frequency of rainy days, and increased rainfall intensity. Cyclonic disturbances though in lower frequency are expected to be of increased intensity, and there is increased risk of storm surges and sea-level rise of 1.3 mm/year on average.

In India, climate change is likely to have severe impacts on key sectors like water (Gosain et al. 2006; Mall et al. 2006). Agriculture sector is expected to decline in production though there may be a short rise in production (Kavi Kumar 2007). The likely impacts of climate change on key sectors like agriculture and water combined with large rural population depending on a climate-sensitive sector for livelihood and with a low adaptive capacity due to poor socioeconomic conditions increase the vulnerability to future climate changes (Shukla et al. 2003; Brenkert and Malone 2005). Over 21 % of population are under below poverty line; the poverty level in rural and urban areas was estimated to be 25.7 % and 13.7 % respectively for the year 2011, and over 60 % of India's population are still rural and dependent on agriculture (Planning Commission 2013).

India is a developing country with low records of historic emissions. It is only after the economic reforms in the 1990s that the economy started to grow and the consumption of fossil fuels increased, leading to raising emissions. Despite its growth in emissions in the last two decades, India's per capita emissions are way below the world average of about 4.5 tonnes per capita (Table 1; Fig. 1).

Electricity sector alone contributes to over 38 % of total greenhouse gas (GHG) emissions. By October 2013, fossil fuels still contributed a large share – approximately two-thirds – of electricity production; coal constitutes about 58.75 % of India's primary energy resources followed by natural gas (8.91 %) and oil (0.52 %), while the rest is provided by nuclear (2.11 %), hydro (17.39 %), and other renewable energy sources (12.32 %) (Source: Ministry of Power 2013). With the economic

Table 1 Emission scenario in India

Years	Economic growth/GDP growth	CO_2 emission in billion tonnes	Per capita emission
1990	1.3	0.98	1.2
1994	7.3	1.23	1.3
2000	4.35	1.48	1.5
2007	9.60	1.99	1.6
2011	8.39	2.01	1.7

Source: NATCOM 2012

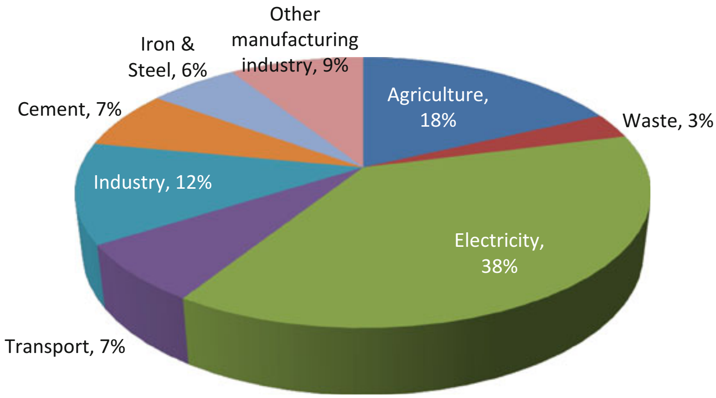

Fig. 1 Emission from various sectors (Source: INCCA 2010)

growth since the 1990s, the emissions have increased from 0.73 billion tonnes in 1994 to 1.02 billion tonnes in 2000 at a compounded annual growth rate (CAGR) of 5.5 % in the electricity sector, meanwhile in 2007, the energy sector emissions grew to 1.3 billion tonnes. A study on projection using different models estimates India's GHG emissions in 2031 to vary from 4.0 billion tonnes to 7.3 billion tonnes of CO_2 (Climate Modelling Forum 2009). The production of coal and power from coal is likely to be the major source of energy production in India in the coming years and shall remain the major cause of GHG emissions (NATCOM 2012).

Given the impacts and vulnerability of climate change in India, adaptation is very necessary and should at least be on a no-regret and co-benefit approach (Sathaye et al. 2006). To alleviate poverty in India, the 12th 5-year plan (2012–2017) aims at a faster economic growth, which shall mean raising GHG emissions as the economic growth is driven by high energy consumption especially produced from fossil fuels. The Government of India is committed to keep its per capita emissions below the world average and in 2009 declared that India's emissions on the intensity of GDP shall be aimed to be reduced by 20–25 % based on the 2005 level by year 2020. The remaining of this chapter will look at financial challenges for mitigation, adaptation, and low-carbon growth in India.

Mitigation and Adaptation Costs

This section looks at financial requirements for successfully implementing Nationally Appropriate Mitigation Actions such as the National and State Action Plans on Climate Change and to take economic growth in a low-carbon path. The financial requirement of scaling of renewable energy is also discussed.

National Action Plan on Climate Change (NAPCC)

In 2007, at the 13th Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC), also known as the Bali conference, developing countries agreed to develop Nationally Appropriate Mitigation Action (NAMA), and subsequently, India released the National Action Plan on Climate Change (NAPCC) in June 2008.

The financial estimates and descriptions of NAPCC's missions are presented in the following table (Table 2).

A sum of about 58 billion US$ shall be required for successful implementation of the National Action Plan on Climate Change through the 12th plan period (2012–2017).

The State Action Plan on Climate Change (SAPCC)

The 16th COP to the UNFCCC held in 2010 at Cancun established the National Adaptation Plan (NAP) process as a way to facilitate effective adaptation planning in least developed and developing countries. NAPs are aimed at reducing vulnerability to the impacts of climate change, by building adaptive capacity and resilience, and to facilitate the integration of climate change adaptation in the countries' plans for economic development. In 2010, the prime minister of India urged the states to develop the State Action Plan on Climate Change (SAPCC) to decentralize NAPCC objectives, while addressing state-specific climate change issues. The SAPCC is a set of regional action plans on climate change prepared by the state government. SAPCCs are to be prepared according to a common and generic framework while providing scope for incorporating state-specific contexts and situations and, at the same time, be integrated into state-level planning process.

The SAPCC aims to mainstream climate change concerns in key sectors, although the states are free to choose their own focus sectors for the SAPCCs. Typical sector mix includes agriculture, forestry and biodiversity, water resources, energy, industries, mining, urban development, health, disaster management, and transport. The SAPCC should give targeted mitigation plans, for example, in energy sector, it should give present GHG emission scenarios, future energy needs, and how SAPCC shall address mitigation through energy efficiency or renewable energy. On the adaptation side, the SAPCC should identify vulnerable sectors and regions and develop adaptation plans.

Table 2 National mission on climate change

	Mission	Brief description	Estimated costs/ benefits for period 2012–2017	Details of financial estimates were derived from
1	National green mission	To reach national target of 33 % land area under forest and tree cover from the current level of 23 %. Mission to be taken up on degraded forest land through direct action by communities, organized through Joint Forest Management (JFM) Committees and guided by Department of Forests	9.42 billion US$	http://moef.nic.in/downloads/public-information/GIM-Report-PMCCC.pdf
2	National mission on energy efficiency	The mission aims to provide binding targets to designated consumers (DCs) to achieve energy efficiency during period 2011–2014. There are about 685 DCs mainly heavy industries and power sector that are required to specific energy consumption reduction targets. The mission works through a market mechanism of Perform, Achieve, and Trade (PAT), wherein the DCs can trade their excess credits to below achievers	The energy efficiency benefits is estimated to be about 12 billion US $ and can reduce about 98 million tonnes of CO_2	http://www.moef.nic.in/downloads/others/Mission-SAPCC-NMEEE.pdf
3	National solar mission	The mission targets include (i) deployment of 20,000 MW of grid-connected solar power by 2022, (ii) 2,000 MW of off-grid solar applications including 20 million solar lights by 2022, (iii) 20 million sq. m. solar thermal collector area, (iv) to create favorable conditions for developing solar	16 billion US$	http://mnre.gov.in/file-manager/UserFiles/draft-jnnsmpd-2.pdf

(*continued*)

Table 2 (continued)

	Mission	Brief description	Estimated costs/ benefits for period 2012–2017	Details of financial estimates were derived from
		manufacturing capability in the country, and (v) support R&D and capacity-building activities to achieve grid parity by 2022. The program also aims to reduce to the cost of solar power along with creating favorable conditions for solar manufacturing industry		
4	National mission on sustainable agriculture	Mission aims to devise strategies to make Indian agriculture more resilient to climate change. Identify and develop new varieties of crops (thermal-resistant crops, alternative cropping patterns, capable of withstanding extreme weather). Orientation of agricultural research systems to monitor and evaluate climate change and recommend changes in agricultural practices. Convergence and integration of traditional knowledge	18 billion US$	http://agricoop.nic.in/imagedefault/whatsnew/nmsagidelines.pdf
5	National water mission	The Overall objective is “Conservation of wter, minimization of wastage, and esuring its equitable distribution both across and within states through integrated water resource management”	4 billion US$.	http://wrmin.nic.in/writereaddata/nwm28756944786.pdf
6	National mission on sustainable habitat	Targets improvements in energy efficiency in buildings, management of solid waste, and accelerating modal shift to mass transport	9 billion US$	http://www.urbanindia.nic.in/programme/uwss/NMSH.pdf

(*continued*)

Table 2 (continued)

	Mission	Brief description	Estimated costs/ benefits for period 2012–2017	Details of financial estimates were derived from
7	National mission on sustaining Himalayan ecosystem	To evolve management measures for sustaining and safeguarding the Himalayan glacier and mountain ecosystem. The mission would seek to address the impacts in Himalayan region and establish community-based management of Himalayan ecosystems	0.2 billion US$	http://dst.gov.in/scientific-programme/NMSHE_June_2010.pdf
8	National mission on strategic knowledge of climate change	Mission to identify the challenges of and the responses to climate change through research. Understand the Socioeconomic impacts of climate change including impact on health, demography, mitigation patterns, and livelihoods of coastal communities. Establishment of network of dedicated climate change-related units in academic and scientific institutions	0.4 billion US$	http://www.dst.gov.in/scientific-programme/nmskcc_july_2010.pdf

Source: National Action Plan on Climate Change, Govt. of India

Many state governments have initiated SAPCCs, thanks to the technical and financial support from multilateral development agencies. The estimation of the costs of implementing SAPCC is cumbersome. A study has observed that existing estimates of costs, for both adaptation and mitigation, in the range of US$3–5 billion over a 5-year period for states of similar size and climate change challenges, are inconsistent mainly because of the variation in the methodologies adopted for vulnerability assessment, development of adaptation plans, and mitigation targets (Mandal et al. 2013). The total financial requirement for implementing the State Action Plans on Climate Change for all 28 Indian states can be about 120 billion US$ for the 5-year period (2012–2017) as estimated from the budgetary provisions provided by the SAPCC of various states.

Low-Carbon and Sustainable Growth

It is necessary for the country to explore all options of energy efficiency and increase renewable energy production (Parikh 2012), which are key efforts in mitigation as well as in low-carbon development. The Government of India established an expert group on low-carbon strategies for inclusive growth. The expert group submitted its final report in 2014, which notes that through appropriate strategies such as increasing share of renewable energy, energy efficiency, sustainable and low-carbon transport, improving carbon sequestration in forestry, and implementing building codes, the projected emission in 2030 can be reduced from 3.6 tonnes per capita to 2.6 tonnes per capita. However, the report estimates that around 834 billion US$ at 2011 prices shall be required over the two decades between 2010 and 2030 (Planning Commission 2014).

Renewable Energy Targets

Starting with the 9th plan period (1997–2002), India accelerated the pace of renewable energy development. India's renewable energy installed capacity has grown at an annual rate of 22 %, rising from about 3.9 gigawatt (GW) in 2002–2003 to about 28 GW in March 2013. Renewable grid power capacity contributes 12.88 % of India's total installed power capacity and is fast becoming an increasingly important part of India's energy mix. The Government of India has ambitious plans for renewable energy production in India. The National Solar Mission alone aims to establish about 22 GW by 2022. The consolidated funds required for grid-connected renewable energy technologies, biomass/agriculture waste, bagasse cogeneration, urban and industrial waste to energy, small hydropower, solar, and wind are about 2.2 billion US$, and off-grid renewable energy programs such as family biogas plants, biomass gasifiers from rural energy supply, decentralized solar photovoltaic system, micro-hydel water mills, and solar thermal systems for water heating and improved cook stoves are also to cost about another 3 billion US$ for a period (2012–2017) (MNRE 2011).

Adaptation and Mitigation Costs Summary

The estimates of mitigation costs vary from available data, and it shall depend on future policies on energy production/consumption and economic growth. The Stern review (2007) estimates that the loss due to climate change could be about 3–5 % of GDP per annum for developing countries, and (Urvashi et al. 2011) estimates for adaptation are in ranges of 70–100 billion US$ per annum for the developing world for the period 2010–2050. Though specific estimates of adaptation costs for India are not available, the estimates provided in State and National Action Plans on Climate Change by the Government of India adds to about 185 billion US$ (2012–2017), which is in range of scientific studies. The expert group on low-carbon growth of the planning commission estimated the costs for pursuing low-carbon growth to be about 834 billion US$ for a two decade period using low-carbon growth model, which is a multi-sectoral, dynamic optimization model that maximizes present discounted value of private consumption subject to commodity supply, natural resource, and technology constraints. Though accurate estimates on adaptation and mitigation are difficult, it can be concluded that India needs billions of dollars over the next two decades to implement its adaptation programs and take in a low-carbon path for economic development. The next section will look at financing options on mitigation and adaptation.

Financing Climate Change Mitigation and Adaptation

Measuring Mitigation and Adaptation Costs

For investment in mitigation and adaptation, India must carefully evaluate the costs and benefits and the possible trade-offs involved in investments. Use of policy instruments like carbon tax must also be understood to know its impacts on the economic growth. About 80 % of India's energy needs are met from fossil fuels; in this context, a number of studies have analyzed the patterns of energy usage and carbon emission and have evaluated the role of pricing and taxation policies in mitigation as well as revenue generation for investment in clean energy (such as Parikh and Gokarn 1993; Das et al. 2007; Murthy et al. 1997). Fisher-Vanden et al. (1997) assessed the option of carbon tax in India and concluded that participating in cap-and-trade (CAT) mechanism would be better for India than carbon taxes. The debate is still on for and against carbon taxes and domestic mitigation efforts that may incur GDP losses. This has led to dilemmas in fixing targeted emission reductions and estimating costs of mitigation.

Measuring the costs and benefits of adaptation at regional level is even cumbersome, which is a challenge in making informed decision or prioritizing domestic investments. Nambi et al. (2010) noted that an assessment of adaptation costs for India, as well as for subregions, is required for effective resource allocation. Adaptation costs estimated by Stern (2007) for India and other developing countries are also argued to be overestimates (Yohe and Tol 2008), which is mainly due to uncertainties in projections and impacts of climate change. This knowledge gap on understanding the mitigation and adaptation costs has led to challenges in estimates on adaptation and mitigation costs in India as noted in section "Adaptation and Mitigation Costs Summary."

Global Climate Finance for India

Based on the principle of equity recognized in global conventions like the UNFCCC, the developed countries are supporting developing and least developed countries in their adaptation and mitigation efforts. The first commitment period of the Kyoto protocol (2005–2012) provided much financial benefits in renewable energy and energy efficiency in India through the Clean Development Mechanism (CDM). India, during the first period of the Kyoto protocol, was a leading CDM beneficiary next only to China with over 470 projects registered with certified emission reduction (CER) close to 17 million tonnes. Almost 85% of CER came from the energy sector on both renewable energy projects and on improving efficiency in nonrenewable energy sector. This not only provided financial benefits close to US$ 300 million at the peak rate of 15 US$ per tonne of emission reduction but also provided scope for energy efficiency and increasing the share of renewable energy. However, CDM projects were not useful in supporting adaptation or sustainable development or helpful in alleviating poverty (Subbarao and Lloyd 2011) (Table 3).

Successful Case of CDM The Bachat Lamp Yojana (BLY) is a public-private partnership program introduced by the Bureau of Energy Efficiency (BEE) to hasten market transformation toward energy-efficient lighting in domestic households by providing compact fluorescent lamp (CFL) at subsidized rate. To reach out to 192 million households and targeted 400 million light points in India by 2011, with an electricity-saving potential of 20,000 MW (by 2011), BLY was the largest CO_2 reduction "program of activity" registered till date with CDM from India (*Source*: Bureau of Energy Efficiency, India. http://www.beeindia.in/schemes/schemes.php?id=1).

Reducing emissions from deforestation and degradation combined with conservation and sustainable management of forests is REDD+, which many developing countries, including India, have been pressing in global UNFCCC negotiations for financial incentives toward carbon mitigation through sustainable management of forests. While the National Green Mission is itself aimed at reducing deforestation

Table 3 Registered CDM project in India

S.I. no.	Sector	No. of projects	No. of CER (annual)	No. of CER (2012)
1	Energy industries (renewable/ nonrenewable sources)	850	69,555,674	19,061,210
2	Manufacturing industries	41	2,074,541	899,459
3	Energy demand	75	2,653,226	1,161,307
4	Waste handling and disposal	22	1,710,094	769,893
5	Metal production	3	877,754	1,257,076
6	Transport	4	964,777	288,670
7	Afforestation and reforestation	5	947,197	114,277
8	Fugitive emissions from fuel (solid, oil, and gas)	1	56,400	56,400
9	Chemical industries	3	320,114	247,946
10	Energy distribution	2	967,681	121,562
Total		1,006	80,127,457	23,977,800

Source: cdmindia.gov.in

and increasing forest cover, the financial requirement to successfully implement the mission can be made available through REDD+ mechanism. Though the REDD + mechanism and the guidelines for financial incentives are not fully developed, India in the future will definitely be looking forward to financial incentives through REDD+.

Financial Support from Multilateral Institutions

The review of funds provided by major multilateral institutions during the period January 2004 to 31 December, 2013, for climate change mitigation and adaptation is evaluated in the table below evaluated in Table 4.

Funding Pattern

In renewable energy projects, much of the funding is on the solar energy sector; the Asian Development Bank (ADB) is supporting the Jawaharlal Nehru National Solar Mission, while the United Nations Development Program (UNDP) supports projects on improving biomass as energy for rural India. In energy efficiency, UNDP is supporting projects on promoting energy efficiency in commercial buildings, Indian railways, and steel rolling mills and in selected small and medium enterprises, which are among the largest consumers of electricity in the industrial sector. On the climate mitigation side, funding is largely on sustainable and low-carbon transport such as metro rails by ADB, which supports through loan for Bangalore and Jaipur metro rail projects, and UNDP is supporting 125 million US$ sustainable transport projects for ten Indian cities through building capacities of government agencies, national/state urban transport departments, and municipal corporations, engaging transport experts in sustainable urban transport planning, and creating awareness on regulations to reduce urban transport emissions.

In climate adaptation, the funding from multilateral agencies includes sustainable coastal areas management by ADB; the World Bank is funding the development of watersheds and irrigated agriculture and water-bodies restoration and management. Further, UNDP and ADB are supporting in the areas of soft adaptation such as institutional building and building capacities of stakeholders on climate change adaptation, as well as supporting the National Action Plan on Climate Change. The multilateral agencies have also been supporting environment improvement programs. The ADB is supporting environment improvement programs in a few cities and World Bank loans are sought for major national environment programs, such as Ganga Action Plans. In recent years, there is also more funding toward disaster risk reduction. UNDP is supporting disaster risk reduction (DRR) in major cities and on DRR and climate change adaptation to extreme events like floods and drought, while the World Bank funding is largely on post-disaster recovery such as tsunami reconstruction and rehabilitation of Uttarakhand state from the flash flood disaster that occurred in June 2013, which caused damages to

Table 4 Financial support from multilateral institutions

Multilateral agency	Renewable energy (million US$)	Energy efficiency (million US$)	Climate change mitigation (million US$)	Climate change adaptation (million US$)	Disaster risk reduction (million US$)	Environment management (million US$)	Total in million US$
Asian Development Bank	3,164	1,234	427	305	381	3,106	8,617
World Bank	672	232	100	1,321	1,431	3,064	6,820
UNDP India	61.33	66.88	131.26	6.51	21	41.49	328.47
Total	3,897.33	1,532.88	658.26	1,632.51	1,833	6,211.49	15,765.47

Source: Compiled by author based on project sheets from respective institutes website the infrastructure like roads and had severe impact on tourism sector and local livelihood and about 250 million US$ was made available for reconstruction.

In addition, major multilateral agencies and technical and financial support from other institutions should be acknowledged. The German Society for International Cooperation (GIZ) supports several climate mitigation and adaptation programs. USAID is supporting a project on low-carbon development; Department for International Development (DFID), International Fund for Agriculture Development (IFAD), Canada AID, Swiss Agency for International Cooperation (SDC), and Japan Bank for International Cooperation (JBIC) are other institutions that are supporting climate mitigation and adaptation and environment management in India.

It can be noted from Table 4 that the total financial support through major multilateral agencies has been about 16 billion US$ for a period 2004–2013, which are partly also as loans that are to be repaid, and given the estimates for adaptation and mitigation efforts such as the National and State Action Plans on Climate Change, which ranges in 100 billion US$, there is a huge challenge to meet these requirements through funding from multilateral agencies.

Conclusion

India has already placed a carbon tax of INR 50 per tonne of coal produced or imported to India, which is used in National Clean Energy Fund (NCEF) since year 2011 and has collected an amount close to six billion US$ by March 2014. The NCEF is using this fund to finance renewable energy projects in India. The expert group on low-carbon strategies for inclusive growth warns that there could be a drop in GDP as a larger share of GDP may need to be diverted for renewable energy, energy efficiency, and investments in low-carbon strategies. Clearly, financing the entire mitigation and adaptation efforts through domestic funds is not feasible given the trade-offs it faces with economic growth and international financial support is required.

The review of financial support in mitigation and adaptation shows that India benefited about 300 million US$ through CDM projects and received about 16 billion US$ as grants and loans from multilateral development agencies. The United Nations Framework Convention on Climate Change (UNFCCC) has established the Green Climate Fund, Adaptation Fund, and Fund for Least Developed Countries (LDCs) to support developing countries (DCs) and LDCs in their effort to adapt to climate change. Accessing such funds by developing countries like India is far from being successful, though India has formally submitted five proposals to the Adaptation Fund Board (ABF). To successfully implement the Nationally Appropriate Mitigation Actions and Adaptation Plans and to steer the economic growth in a low-carbon pathway, India will require continued financial and technical support from multilateral agencies by engaging in global climate change negotiations; India should actively push for continued support of developed countries in adaptation and mitigation finance. India's commitment to low-carbon and climate-resilient economic development needs appreciation from developed world through financial and technical support. Though agencies like World Bank have supporting post-disaster rehabilitation like in Uttarakhand, future burden on domestic financial abilities to meet the loss and damage from such extreme weather may become more difficult. International aid cannot solely be depended in the future for post-disaster reconstruction and rehabilitation, and India and other developing countries will be actively looking forward for global support in the climate change negotiations for loss and damage compensation also that started in COP 19 at Warsaw.

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From Risk to Opportunity: Climate Change and Flood Policy in Bangladesh

Muhammad Jahedul Huq and Louise Bracken

Contents

Abstract

This study identifies current gaps and opportunities of existing flood regulatory frameworks and national climate change strategies of Bangladesh. In so doing, the research develops a framework to reconcile the interest of land, water, and people in order to reduce the vulnerability of extreme flooding and develop strategies for future flood management. The study reveals that the existing flood

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regulatory framework is only effective for relief and response during times of flooding but has significant gaps and inadequate provisions to increase communities' adaptive capacity and resilience to deal with future flooding vulnerability under climate change. The flood management system also suffers from a lack of coordination, complex institutional frameworks, and budgetary constraints. The findings of the study also reveal that people's/communities' participation is at a very early state in flood-related project formulation and implementation, and they are totally absent at the level of flood management committees. In addition, the study strongly urges introduction of evidence-based flood policy formulation to reconcile the interest of land, water, and people. Working in this way will give people and communities a voice in the decision-making process, ensure the participation of vulnerable people in decision-making around flooding, and take immediate initiatives to fill the existing gaps and weaknesses of flood management system in Bangladesh.

Keywords
Flood • Disaster risk reduction • Climate change adaptation • Resilience • Bangladesh

Introduction

Fluvial flooding is unquestionably the most recurrent and devastating natural disaster in Bangladesh, and further increases are estimated due to climate change projections (GOB 2009a, b; Mirza et al. 2003; Mirza 2002; Agrawala et al. 2003; Ali 2011; Dasgupta 2007). Fluvial flooding occurs when rivers overflow and burst their banks, due to high or intense rainfall which flows into them. Typically, fluvial flooding in Bangladesh occurs when discharges from several major rivers coincide within a short period of time with heavy monsoon rainfall. It is stated that unprecedented population growth, continuous wetland encroachment, and unplanned increases of infrastructure on floodplains in Bangladesh will accelerate this flooding vulnerability under climate change. This increased flooding vulnerability and uncertainty will diminish the flexibility of the country's ability to react to flood events as well as the appropriateness of traditional flood management strategies. Consequently, changes in duration, depth, and timing of fluvial flooding might bring drastic changes in the country's subsistent agriculture (Younus 2010) and livelihood of the poor in particular, with the possible result of pushing more people below the poverty line (Mirza 2002). Hofer and Messerli (2006) contend that in the last two decades, the people of Bangladesh have demonstrated resilience to flooding in the form of autonomous adaptation, but at the present time, their ability is exhausted due to the changing pattern of floods in terms of frequency, intensity, and time of occurrence. Furthermore, historical and contemporary data clearly demonstrate that the impact of floods is a key factor hindering the development process of Bangladesh.

The study presented follows a critical review method in order to investigate and strengthen flood management policies to facilitate adaptation and to increase resilience of those communities most vulnerable under climate change in Bangladesh (Samuels et al. 2006; Mirza 2002). This paper begins presenting a brief overview of key concepts (disaster risk reduction, climate change adaptation, and resilience) and the notion of people-centered policy as a framework of research. Section "Flood Management in Bangladesh" then provides an evaluation of existing flood management strategies in Bangladesh including the regulatory framework around flooding; a critical review of existing flood regulatory frameworks to address flooding under climate change with special regard to the contribution of resilience. Climate change adaption (CCA) and disaster risk reduction (DRR) are found in section "Review of Flood Regulatory Frameworks in the Context of DRR, CCA, and Resilience". Section "Key Issues, Gaps, and Constraints" identifies the opportunities and constraints of existing flood management policies to reduce the vulnerability due to extreme flooding and potential damages and transferring risks in terms of changes in monsoon, temperature, and sea level rise for long-term climate change. Conclusions are reported in section "Conclusion."

Analytical Framework

This section provides an analytical framework for the concepts of disaster risk reduction (DRR), climate change adaptation (CCA), and resilience. These three concepts provide a suitable analytical framework, which focuses on people-centered policy (development) within the context of flood- and climate change-induced vulnerability. In effect, this foundation for analysis highlights the importance of people's participation in decision-making in increasing the effectiveness of flood vulnerability reduction under climate change.

Understanding the Key Concepts

Considering the notion of risk and vulnerability as the key underlying concept of DRR (UNISDR 2004; Concern 2005; White et al. 2004), this paper views DRR as "the systematic development and application of policies, strategies and practices to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevent) or to limit (mitigate and prepare) adverse impacts of hazards, within the broader context of sustainable development" (UNISDR 2002, p. 25). Therefore, DRR adopts a broad range of guidelines including policy/regulatory issues and planning practices to fill the gaps between development and humanitarian works to protect lives and assets by reducing vulnerabilities and enhancing resilience (Concern 2005; Mitchell and van Aalst 2008; Twigg 2004).

Similarly, the conceptualization of CCA includes an open process or ongoing actions to improve the condition, measures, or strategies to reduce vulnerability and to introduce new initiatives to increase resilience in order to cope or to adjust with climate change-associated adverse effects (Andreasen 2011; Schipper 2004).

So, adaptation can be a specific action, for instance, changing cropping pattern, employing water efficient irrigation practices in drought-prone areas, planting saline-tolerant rice varieties, and a system change such as diversifying livelihoods. Additionally, it incorporates policy and institutional reform, which might change particular activities or make available additional services to vulnerable people, which in turn may help them to make better decisions (Raihan et al. 2010). Therefore, in the context of DRR and CCA, this paper characterizes resilience as the long-term ability or capacity of individuals, communities, organizations, or countries to take/make effective strategies and measures to reduce and to cope with and respond to extreme events as well as organize recovery after these shocks (Twigg 2001, 2009; IFRC 2012; UNISDR 2002).

The Framework of Research: People-Centered Policy Development

It has been established that the relationship between nature and society is complex and that their association is nonlinear. Nature and society also interact in a coupled and integrated way. Hence the study uses the concept of socio-ecological resilience to examine the floods in Bangladesh. The socio-ecological resilience approach greatly enhances understanding the nature of processes and socio-ecological system response, which in turn facilitates achieving socioeconomic development as well as maintaining a healthy ecosystem of rivers and floodplains simultaneously. Here, socio-ecological resilience is the capacity or ability of a human and physical environment to respond or absorb or shape each other within their own domain in an informed manner (Adger 2000; Peterson 2000). Moreover, this approach is a tool rather than being a theory that engages different stakeholders, particularly the poor and most vulnerable communities, in the decision-making process to reduce flood risks and floodplain development (Warner et al. 2002). The approach also incorporates new ideas from resilience in order to better analyze and manage transitions to more sustainable development pathways in social-ecological systems.

The concept of people-centered policy integrates DRR and CCA in development policies and programs. Thus DRR polices incorporate the preferences/priorities of communities most at risk. It also follows a bottom-up approach by power sharing and access to justice against discrimination and exclusion. Moreover, this approach not only gives the primary responsibility to vulnerable communities to protect their own land and properties from floods but also creates an opportunity to perform active citizenship through collective action to reduce flood risks (Johnson et al. 2007, 2008). Figure 1 provides an overview of people-centered policy development, which places the poor and vulnerable community at the center of the policy formulation process. This facilitates the participation of flood-afflicted groups from project formulation to its implementation. The diagram represents three different circles, which are denoted as DRR, CCA, and resilience. The characteristics of these three concepts are different from one another, but there is an increasing recognition that DRR, CCA, and resilience share a common focus in reducing vulnerabilities and thus contribute to sustainable

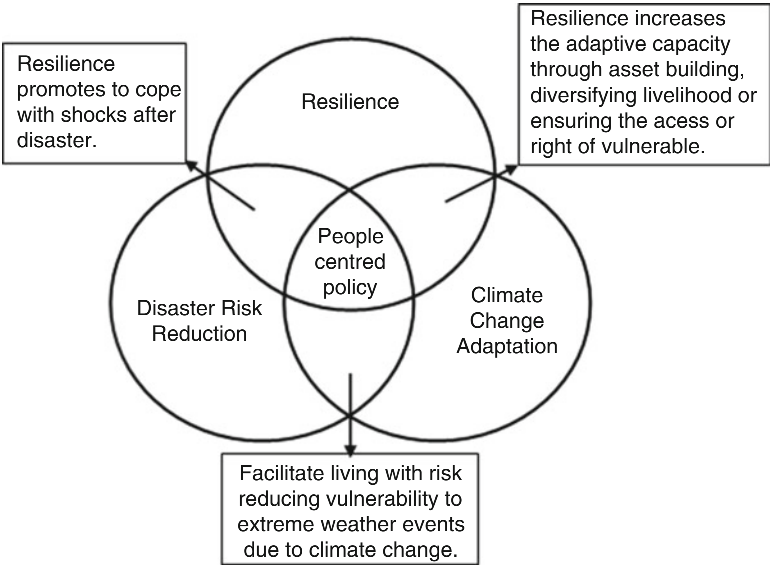

Fig. 1 Conceptual framework for people-centered policy (development)

development (CEPA 2012). In so doing, this study argues that a people-centered flood policy framework provides support to increase and build people's resilience and adaptive capacity through diversifying livelihoods and by ensuring access and rights of poor and socially disadvantaged groups to reduce vulnerabilities to flooding under climate change.

Flood Management in Bangladesh

Flood management in Bangladesh has continuously evolved over the last 60 years from relief rehabilitation, to flood prevention, toward flood preparedness. In early periods, particularly before the political partition of the Indian subcontinent, there were no government-led flood management systems. In the 1960s, after a series of disastrous floods, large-scale engineering structures gained importance to control flood water in order to introduce high-yielding rice varieties to meet the demand of a growing population (Haque and Zaman 1993; Haskoning 2003; Cook 2010). After the independence of the country in 1971, small-scale flood control and drainage projects were implemented by the World Bank, the Asian Development Bank (ADB), and the Dutch government. Similarly, after the floods of 1987 and 1988, the Flood Action Plan (FAP) was formulated with the help of the United Nations Development Programme (UNDP) and the World Bank, focusing on traditional large structure-oriented plans. However, actual actions have not been taken yet due to people's resistance against structural measures. Later in 1995, FAP was accepted by the Government of Bangladesh (GOB), and donor agencies incorporated local people in partnership with experts and professionals in water management (Chadwick and Datta 2003; Sultana et al. 2008).

In 1998 a disastrous flood brought a new dimension to flood management strategy in Bangladesh emphasizing “integrated water management, floodplain morphology and flood forecasting and warning” (UNEP 2002, p. 35). This strategy takes into account livelihood development and reduces the vulnerability of the most disadvantaged in society. However, the big floods of 1987, 1988, and 1998 also brought changes in policies, in particular the formulation of new plans/strategies and incorporation of new institutions for future flood management. As Sultana et al. (2008, p. 7) explain:

> . . .the 1987 and 1988 floods resulted in the FAP process which led to debate over policy directions and delayed any structural works. These floods also catalyzed changes in policy direction and brought forward the involvement of new actors who introduced new concepts to public discourse such as compartmentalization. Similarly, environmentalist and civil society lobbies emphasized land-use planning and flood retention in 1998, indicating a major change from the ‘engineering coalition’ and its policy beliefs that had dominated much of the previous 50 years.

At present, there are different regulatory frameworks and stakeholders (Fig. 2) involved directly and indirectly at different levels of flood management in Bangladesh. The Bangladesh Water Development Board (BWDB) is the principal national institution concerned with flood management and disseminates flood information to all related government departments and organizations. Additionally, the Ministry of Water Resources (MOWR) and recently (2012) established Ministry of Disaster Management and Relief (MDMR) act as national level coordinators of

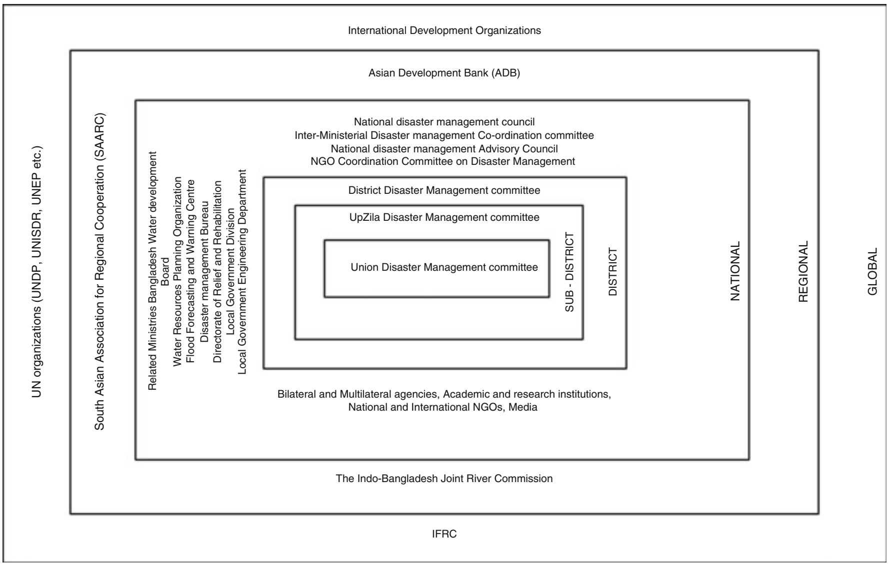

Fig. 2 Different levels of stakeholders’ engagement in flood management in Bangladesh

flood management relating to water and disaster management, respectively. However, during flood events, overall coordination is the responsibility of the latter ministries and the Inter-Ministerial Disaster Management Committee. Although Bangladesh has no specific plans and policies for flood risk management, the National Water Policy and Water Management Plan is especially formulated for effective management of the country's flooding problem. A Comprehensive National Strategy for Disaster Management and Standing Orders on Disaster (GOB 2010a) has also been developed, which defines the roles and responsibilities of different agencies in different stages of disaster management. The following section examines these national flood regulatory frameworks to identify existing efforts and responses in the context of risk reduction, adaptation, and resilience to flooding under climate change.

Review of Flood Regulatory Frameworks in the Context of DRR, CCA, and Resilience

Although flooding is an annual phenomenon in Bangladesh and costs about 0.5–1.5 % of total GDP (World Bank 2010), the country has no specific flood regulatory frameworks. Here, flood regulatory frameworks mean a set of acts, policies, and plans/strategies, which are related to flood management in Bangladesh. There are few regional and international regulations which Bangladesh considers for flood management. However, after the independence of the country in 1971, major changes in flood regulatory frameworks occurred after the devastation caused by floods in 1987 and 1988 and the beginning of the country's new political era in 1990 (Sultana et al. 2008; Chadwick and Datta 2003; Pal et al. 2011). Section "Review of Flood Regulatory Frameworks in the Context of DRR, CCA, and Resilience" consists of three subsections which present a critical analysis of the legal frameworks, sectoral policies, and different planning documents in order to identify the gaps and opportunities of existing flood management in Bangladesh.

Review of National Legal Frameworks

The Standing Order on Disaster (SOD)

The SOD was first prepared in 1997 and later revised in 1999. SOD is formulated to "outline the role and responsibilities of the ministries, divisions, agencies, organizations, committees, public representatives and citizens to cope with any natural disaster" (GOB 2010a, p. i). It also instructs all concerned authorities and responsible persons to follow respective guidelines during the normal time for disaster preparedness, emergency period, precautionary and warning stage, disaster stage, and post-disaster stage. Moreover, the order also provides an institutional mechanism to ensure the coordination of disaster-related activities among and within the different levels of actors. Significant changes to SOD took place in 2010 when the recommendations of the World Conference on Disaster Risk Reduction (2005) on vulnerability to climate change were adopted. The SOD also evolved when Bangladesh became a signatory to the Hyogo Framework Action (HFA) (2005–2015), which mainstreamed DRR and CCA in all natural disasters.

At present, disaster management in Bangladesh is regulated under the SOD and follows reactive approaches of disaster management, particularly centered on traditional relief and responses during and post disaster. SOD adopted DRR in 2008 and highlighted disaster preparedness as the basis for autonomous adaptation, but in reality it is not present at the local level (Haque and Haque 2009), and there is no contingency plan for flood management. Additionally, SOD does not clearly define the roles and participation of affected communities. A study by Rashid (2008) on the implementation of SOD at the local level found that most Union Disaster Management Committee (UDMC) members have no knowledge about SOD nor their roles and responsibilities. Resource constraints to execute disaster management plans are also a challenge. As a result, local-level disaster management committees only function during the disaster period for relief distribution and response operations. Although this regulation clearly defines the roles and responsibilities of each institution, it does not provide any indicative guideline for reducing risks and vulnerabilities, e.g., building code for floods, or specific directions such as spatial planning for infrastructure (road, culvert, and rail).

National Disaster Management Act (DMA)

The DMA (2011) is enacted to enforce the SOD, especially to ensure the accountability of all disaster-related agencies and persons, who are responsible to reduce disaster risks for protecting people's lives, livelihoods, and assets. The key provision of the DMA is to establish a disaster management department to coordinate the activities of all government and development partners. It also gives power to the president to declare a "national disaster" and to form a "national disaster fund" (MODMR 2012b). Most importantly, this act gives preference to the ultra-poor and socially excluded people in DRR and emergency response activities. However, this act inherited its strategy from the country's traditional disaster management approach – relief and rehabilitation – and is therefore reactive. It calls for flood risk assessment before doing any construction but does not give any instruction to real estate developers. It does not even provide any opportunities to perform collective actions for flood risk reduction. Additionally, it proposes punishment for negligence of emergency response, but does not make any legal provision for those who are responsible to increase people's vulnerability by occupying floodplains or flood flow zones for further use.

Draft Water Act

The draft water act (2012) is prepared to adopt and to make effective the National Water Policy (1999). This draft act entrusts the Executive Committee of the National Water Council to ensure integrated, equitable, and sustainable management, development, utilization, and protection of water resources of the country. However, it does not directly deal with climate change and floods in Bangladesh, but makes provisions for catchment-wide river management. It also insists on exchanging regional data and information for transboundary rivers with neighboring countries for long-term water resources as well as flood planning and management. Additionally, the draft act emphasizes not to build any infrastructures that may affect the natural flow of rivers, but allows for embankments along the major rivers to protect people and their assets from future floods. It does not give any clear direction ordering conservation and protection of other wetlands and floodplains as designated flood flow zones, which might indirectly induce unplanned use of floodplains to meet the growing demand of land. Moreover, people's participation in water resource planning and management is not included in the draft act, while the National Water Policy operates to ensure stakeholder engagement at all levels.

Review of National Sectoral Policies

As previously mentioned, Bangladesh has no single flood management policy. But national water policy plays an important role in directing and guiding reduction and management of flood-related problems. Apart from this, there are other policies, which are directly related to causes, impacts and management of flooding in Bangladesh. The following policy matrix (Table 1) provides an overview of those policy objectives and their key thrusts, which are focused on risk reduction, adaptation and resilience to flooding.

Review of National Plans/Strategies

National Adaptation Programme of Action (NAPA)

NAPA-2009 is an updated and revised version of NAPA-2005, which originated under the guidance of the United Nations Framework Convention on Climate Change (UNFCCC) in response to the Seventh Conference of Parties to address the countries' urgent and immediate actions in regard to CC (GOB 2005). The new plan identified 45 adaptation measures classified into six broad thematic areas, which were intended to contribute toward enhancing adaptive capacities and resilience of vulnerable communities. The revised NAPA set its strategic goals to facilitate DRR, on sustainable development and also on institutional capacity building to accelerate adaptation. However, this plan has no special measures. In fact no provisions for making space for water, to reduce flood risk and vulnerability, are made. Although NAPA claims to follow a participatory approach during preparation, it does not incorporate local-level stakeholders, and even the role of community and non-state actors in project implementation is not clearly spelled out. NAPA-2009 does not provide any guidelines to mainstream the identified adaptation measures in other government plans. Moreover, the plan lacks the institutional framework and economic capacity to put all adaptation measures into operation.

Table 1 Matrix of flood-related policies

Sectoral policy and implementing ministry	Objective(s)	Key policy thrusts related with DRR, CCA, and resilience
National Disaster Policy (draft) (2012), Ministry of Disaster Management and Relief	Reducing people's vulnerability and unacceptable risks through effective response and recovery management at all levels	Focuses on people's participation in disaster management (DM), flood-based risk management programs using social vulnerability analysis and participation of co-riparian countries on data exchange for flood forecasting and early warning dissemination
		Section 8 raises the profile of DM in different sectors like agriculture, education, health, water, food security, land use, and planning to enhance the adaptive capacity and resilience of the community
		Calls for humanitarian assistance during and after floods to cope with that adverse effects and put importance on social safety nets to increase the resilience of poor and vulnerability communities
		This draft policy also details out the responsibilities of different state and non-state actors. But it lacks specifics contribution from the annual budget and coordination mechanism among the institutions and actors
National Agriculture Policy (final draft) (2010), Ministry of Agriculture	Increase food production to meet the growing demand and to attain food security at all levels	This revised policy identifies CC and increasing intensity and frequency of floods as key threats for future agriculture and calls for research to develop weather forecasting and early warning for the primary economic sector, to invent new flood tolerant varieties and deep water crop management
		Under section 5 in the policy (agriculture extension), it proposes a bottom-up approach to include the needs of farmers and to provide extension services to "landless, marginal, small, medium, large with special emphasis on women and youth"
		It also highlights promotion of suitable crops considering different agroecological zones and expertise of farmers

(*continued*)

Table 1 (continued)

Sectoral policy and implementing ministry	Objective(s)	Key policy thrusts related with DRR, CCA, and resilience
		To increase resilience, the policy suggests adequate financial support and ensuring the availability of agricultural commodities (fertilizer, seeds, irrigation) to all particularly, small, marginal, and tenant farmers to enhance productivity and also makes provision for special programs for low-lying areas of the country to protect crops from flood
		Recommends special assistance and agricultural rehabilitation during and after disaster, respectively, introduces insurance scheme and generates income activities for affected farmers to cope and adapt with respective disasters
National Wetland Policy (2009), Ministry of Land	Sustainable use of wetland to increase and maintenance of the existing level of biological diversity including fish resources and to promote the value of wetland for economic development	Revenue-driven rural wetland management motivates this legislation
		No specific mention to use and conserve wetlands for flood management
		There are few condition/obligations of leasing wetland like give preference to poor and socially disadvantaged fishing community, ensure the irrigation water during dry season, which might increase the resilience of fishing and farming community
National Urban Sector Policy (2006), Ministry of Local Government, Rural Development and Cooperatives	Ensure sustainable urban development through decentralized development, optimal utilization of land use, functional local government, and participation of community	Focuses on local urban planning including land-use zoning, incorporation of green infrastructures, and restrictions of housing in flood-prone areas and suggests protecting environmentally sensitive areas to reduce the vulnerability of flooding
		It also deals with the improvement and rehabilitation of slums, housing for the poor, and different measures to cut the number of poor. Additionally, it emphasizes community participation for flood preparedness and response capabilities

(*continued*)

Table 1 (continued)

Sectoral policy and implementing ministry	Objective(s)	Key policy thrusts related with DRR, CCA, and resilience
National Land Use Policy (2001), Ministry of Land	Land zoning to control unplanned land use and loss of croplands, sustainable land use comply with natural environment and to ensure better utilization for economic development of the country	Although the policy is very much diverted to ensuring economic development of the country, it also recommends ensuring environment sustainability through protection of the natural environment to reduce disaster vulnerability
		It does not make any direct observation on climate change, flooding, and the role of land-use planning
		It identifies unplanned urbanization, and low land filling might increase the intensity of flooding, but it does not suggest any specific measures to make space for the water or make room for rivers
		It proposes construction of road cum flood embankments in a way that will not affect the natural flow of water and minimize encroachment of wetlands
National Rural Development Policy (2001), Ministry of Local Government, Rural Development and Cooperatives	Rural poverty reduction and socioeconomic improvement through increasing food production, development of physical infrastructure and skill human resources, ensuring participation of women with men, and promoting effective local government system	This policy gives priority in financing and implementing flood control project and encourage environment friendly land use to increase food production. Besides, it also allows use of unutilized low lands for cultivation
		It highlights poor and socially disadvantaged communities for housing, access to credit, insurance for agriculture, health, education, women empowerment, etc. to increase adaptive capacity and resilience to future flooding
National Water Policy (1999), Ministry of Water Resources	Maximum and efficient utilization of all available water resources in order to attain self sufficiency in food production and managing all water-related disasters	This policy does not mention any specific measures on flood and CC but indirectly addresses, which might facilitate DRR and adaptation to climate change
		In section 4.1 of the policy, it emphasis on comanagement of international rivers and exchange of data and information (hydrology, morphology, changing basins characteristics, and flood early warning) to understand and management of existing and future extreme events

(*continued*)

Table 1 (continued)

Sectoral policy and implementing ministry	Objective(s)	Key policy thrusts related with DRR, CCA, and resilience
		Policy also calls for developing flood forecasting, flood-proofing systems, i.e., designating flood risk zones, flood embankments for urban and economic importance areas, raising plinth of infrastructure in rural areas, and cropping patter adjustment to cope with extreme flooding
		Section 4.13 of the policy accounts for the preservation of *haor*, *boar*, and *beels* to gain optimum economic benefits rather than conservation for retaining flood water and a source of livelihood of rural people
		Most importantly, it highlights stakeholder participation as an "integral part of water resource management" and makes a provision to engage target groups in all water-related projects
National Forests Policy (1994), Ministry of Environment and Forests	Afforestation, enriching biological diversity, control forest depletion and social forestry for poverty reduction	This policy starts with the recognition of forestry to reduce the impact of global warming and CC and to maintain an ecological balance
		It demands plantation on flood embankments and river banks and highlights the need to keep 20 % of total country's land as forest – in order to decrease surface runoff and soil erosion to avert disastrous flooding and rising river beds due to sedimentation
National Environmental Policy and Action Plan (1992), Ministry of Environment and Forests	Protecting natural environment, controlling pollutions and sustainable use of natural resources	This policy does not deal with CC but specially recommends for control and management of those factors, which might exacerbate flooding risks and vulnerabilities under climate change

Source: MOWR 1999; WARPO 2001, MOFDM 2012; MOL 2009; 2001; MOEF 1992, 1994; MOA 2010; MOLGRD&C 2006; Haque and Haque 2009; Nishat et al. 2011; IUCN 2008; Pal et al. 2011; MODMR 2012a

Bangladesh Climate Change Strategy and Action Plan (BCCSAP)

BCCSAP, as an extension of NAPA, was prepared in 2008 and later revised in 2009. This 10-year (2009–2018) plan had 44 programs grouped into six broad sectoral pillars in order to "build the capacity and resilience of the country to meet the challenge of climate change" (GOB 2009b, p. 27). Following a sectoral approach, the plan of action emphasized infrastructure-based flood control management including construction of embankments, dikes, and excavation of rivers to increase the water retention capacity. Similarly, it suggested improvement of early warning and community capacity building for flood preparedness and development of insurance schemes for future risk management. As a way to support resilience, it developed nine programs under the theme of food security, social protection, and health and six programs to strengthen institutional adaptive capacity and mainstream CC into regulatory frameworks. In this context, GOB formed the Climate Change Trust Fund (BCCTF) to execute this plan and made a provision of US$100 million per year since 2009 from the annual national budget.

Despite the fact that Bangladesh has suffered and is still suffering due to heavily engineered flood control projects developed in the 1990s, BCCSAP surprisingly endorses similar programs to reduce future flood risks (Alam et al. 2011). For instance, Bangladesh Water Development Board (BWDB) under the Ministry of Water Resources is responsible for constructing highly engineered flood infrastructure (e.g., embankment, dam, etc.) and receives the largest budget, 36 % of the allocation made under BCCTF (Khan 2012). This plan of action is developed without any policy reference and does not give any policy direction to formulate any national climate change policy. Like NAPA, this plan is prepared by experts and consultants to the detriment of the landless and the sharecropper. Poor fishermen's participation is ignored during its formulation process. Moreover, it does not focus on any regional cooperation for flood risk reduction, which is an imperative to address flooding under climate change in Bangladesh (Alam et al. 2011; Raihan et al. 2010).

National Water Management Plan (NWMP)

The NWMP was developed in 2001 and adopted by the GOB in 2004. It provides a framework for development, management, and use of water resources aiming to attain the country's national development goals. This plan adopts light structural measures in the name of river improvement programs such as flood control and drainage schemes to increase food production. It also encourages improvement of flood forecasting and flood preparedness for flood risk management and advocates involvement of local people in water resource planning and management. Moreover, it proposes flood proofing of 3.5 million dwellings in river islands and *haor* areas and raises all national and regional roads and railways for temporary safe haven for flood victims and movement during flood emergencies. It is frustrating that only a very small part of the plan is implemented. Lack of continuous and sufficient funding, and clear authority and coordination of the agencies involved are also major challenges to implementing and managing flood-related interventions.

National Sustainable Development Strategy (NSDS)

NSDS (2008) has been developed with the vision to "ensure sustained economic growth, environmental protection and social justice which implies improvement of livelihood options of the people, reduction of poverty; ensuring wise use of natural resources, good governance and people's participation" (DOE 2008, p. i). It recognizes natural disaster (flood and cyclone) and climate change as the key challenges to sustainable development in Bangladesh. It identifies the impact of floods on the national economy and infrastructure as well as on human security due to future increased vulnerability. But the strategy focuses on future water security to ensure food security of the country rather than a well-defined flood risk management under climate change. The proposed strategies under the theme of agriculture and rural development, and social security and protection might contribute toward increasing resilience and adaptation with climate change-induced flood risks. Although this strategy emphasizes peoples' participation at all levels to attain sustainable development in Bangladesh, its implementation is hampered by a lack of an institutional framework and absence of coordination with other regulatory frameworks.

National Plan for Disaster Management (NPDM)

The NPDM (2010–2015) aims to introduce a comprehensive risk reduction culture and thus bring changes to strengthen institutional capacity for better disaster recovery and response management at all levels. This is why it makes provisions for accountability of institutions, involvement of all stakeholders, and empowerment of at-risk communities. It indicates all relevant sectoral plans to adopt DRR and CCA, where the NPDM will act as a basic guideline. Additionally, this plan makes a requirement to prepare all local-level risk assessments and risk reduction action plans by 2010. But up to October 2009, this had only taken place in 622 Union Councils from 16 districts (of Bangladesh's 4451 Union Councils in 64 districts) under the project of Comprehensive Disaster Management Project (CDMP-I) (CDMP 2010). However, meteorological data and information on climate change at the lowest level are not available in Bangladesh, and the guideline for preparing local-level risk assessment does not adequately address climate change (CDMP 2010). Similarly, this plan is not developed and does not create space for participation of vulnerable communities in its implementation. This plan announced two distinct funds for relief and rehabilitation, and risk reduction, respectively, but these have not yet been formed.

Sixth Five-Year Plan

The fundamental objective of the sixth 5-year (2011–2015) plan is to "develop strategies, policies, and institutions that allow Bangladesh to accelerate growth and reduce poverty" (GOB 2010b, p. 2). This plan identifies seven key priority areas, including environmental sustainability. This broad thematic area includes important initiatives which might reduce flooding vulnerability under climate change. These initiatives consist of increasing forest coverage to 15 % by 2015, restoring and protecting wetlands and natural water flows in line with conservation act, implementing land zoning for sustainable management of land and water, and also integrating DRR and CCA into development project design and budgetary allocations. As a way of increasing resilience, the plan suggests that the government should allocate more resources for social protection and promote pro-poor natural resource management. However, very little has been done in the past due to a limited budget and resource constraints. Since DRR has no specific budget and is not yet mainstreamed in all sectoral plans and institutions, DMB as well as its local committees cannot implement any interventions.

Perspective Plan of Bangladesh

The perspective plan (2010–2021) recognizes the impacts of climate change on development, particularly acknowledging the impact of flooding due to climate change on the national economy, and identifies it as one of the key challenges to becoming a middle-income country by 2012. This plan defines flooding as a problem of "excessive water during wet/monsoon season" and recommends mixed (structural and nonstructural) measures for flood prevention. Further emphasis is put on constructing new embankments and strengthening flood forecasting and warning for future flood risk reduction. Similarly, it points out adaptation to climate change as a prime force for the development of Bangladesh. As the plan (GOB 2010c, p. 110) states: "adaptation to increased flooding would require full flood protection embankments along the major and medium riverbanks. Since the country's population continues to grow resulting in huge pressures for settlements to extend into flood vulnerable zones, embankments are *sine qua non* for flood protection in Bangladesh." In addition, the plan outlines a number of key strategies including mainstreaming climate change issues in sectoral policies, plans, and programs, facilitating adaptation to climate change, and increasing institutional capacity. These strategies have to be carried out in order to enhance resilience to climate risks and impacts mobilizing resources from bilateral, multilateral, and other international donors.

Key Issues, Gaps, and Constraints

This section details the findings of the study and analysis based on the research questions. Analysis and discussion is conducted in light of the theoretical framework and review of flood regulatory frameworks of Bangladesh.

Risk-Based Approach

Considering risk as the probability of occurrence and adverse consequence of flooding, flood regulatory frameworks in Bangladesh adopt a technocratic approach to flood management, which alters the risks by modifying the physical vulnerability of the people and built environment in order to limit the losses from flooding (Warner et al. 2002; Sayers et al. 2002; Samuels et al. 2006). These planning policies emphasize site-specific flood risk assessment to determine the flooding vulnerability of a particular area and suggest engineering solutions as mitigation strategies to eliminate or reduce the level of risk (DMB 2010). Although the planning policies propose flood risk assessment to limit the extent of development in flood-prone areas, it promotes more urbanization to fulfill the short-term demand of housing and carefully avoids the natural flood risk reduction as a long-term objective (MOWR 1999; WARPO 2001). Therefore, the provision of "full protection against floods" for urban areas might encourage others to develop floodplains into new urban areas. This in turn exacerbates the conflict between land and water in the future. In addition, this way of occupying floodplains has a detrimental effect on the natural environment as it hampers biological productivity and reduces the ecosystem services.

To increase the resilience of communities, planning policies offer mostly short-term DRR rather than reduction of vulnerabilities per se. The flood management decision-making process is developed on the basis of the outcome of the risk-based approach, which avoids the root causes of vulnerability. In this instance, risk is therefore seen as a technocratic and scientific view of disaster, which blames nature and its hazards as the causes of people's vulnerability (Collins 2009; Wisner et al. 2004). This is interpreted as the reason why authorities avoid the social, political, and economic aspects of flooding vulnerability and promote flood-proofing infrastructure for flood risk reduction. The root causes of anthropogenic drivers (i.e., high population growth, land-use change) are the pathways to increase the intensity of effects of flooding, which are not taken into account. Research has found that people who live in floodplains and are most vulnerable to flooding are the poor (Walker and Burningham 2011). Thus hazard risk reduction rather than vulnerability will not enhance the people's adaptive capacity and improve their socioeconomic resilience. Furthermore, the key objective of all policy frameworks is to increase or ensure economic growth and economic development of the country. As a result, the market-based policy frameworks do not increase the adaptive capacity and resilience of the poor and socially marginalized groups but rather increase flood risks of the country by deteriorating the natural environment (Alam 2008).

As a nonstructural measure, Flood Forecasting and Early Warning (FFEW) in Bangladesh is not adequate due to limited communication and dissemination facilities (USAID 2008). These include limitation of accuracy and reliability of forecast, limited coverage, insufficient coordination and feedback, and ambiguity of warning messages (ADB 2006). Here, river water level is used for FFEW, which is a concept not well understood by the community. Additionally, the warning message does not carry other relevant information such as the expected flood water travel time in respective areas, potential inundated area, and water depth due to flooding. The inundation map, which is prepared by the flood forecasting and warning center, does not cover subdistrict (*Thana*) level flooding information. Moreover, inadequate access to upstream inflows and rainfall data and information from India is still a key weakness for accurate flood forecasting (MOWR 2006; ADB 2006).

(Social) Justice and Equity

The flood regulatory frameworks of Bangladesh adopt a top-down and heavily engineered approach (Rasul and Chowdhury 2010) as well as the principles of maximum utility, whereas sustainable flood management requires the principles of equality and vulnerability (Johnson et al. 2008; Brown and Damery 2002). The principle of maximum utility uses cost-benefit analysis for decision-making, which places emphasis on only the economic efficiency of risk reduction. As a consequence, it favors the well-being of majority of taxpayers or economic importance areas and ignores the communities at risk in the rural areas (Newborne 2009; Samuels et al. 2006). This principle is very much evident in most flood-related policies of Bangladesh. Additionally, most of the flood management frameworks are prepared by experts and consultants where people's participation or a deliberate process with real flood sufferers is absent. There is no representation from vulnerable or flood-affected communities in local-level disaster management committees. This technocratic approach of flood risk identification and management is a barrier to attain a fair and sustainable flood management policy in practice.

The two key documents (NAPA and BCCSAP) of climate change in Bangladesh have been prepared and revised without any participation of vulnerable communities (GOB 2009a, b; Raihan et al. 2010; Alam et al. 2011). As mentioned previously, NAPA follows an expert-driven and impact-based approach for adaptation formulation. It therefore misses the key features of vulnerability and is likely to lead to ineffective resources use. It might also intensify the vulnerability of the most vulnerable (Ayers 2011). Similarly, the sectoral approach of adaptation to climate change in BCCSAP left behind the poor, landless, and socially disadvantaged communities' involvement and priorities in respective sectoral programs, although it indicates mainstreaming vulnerable communities including women and children (Alam et al. 2011). These observations make it clear that the issue of vulnerability and targeting the vulnerable are inadequately addressed in existing flood management frameworks including policy making. This "multifaceted nature of vulnerability" might be a key challenge for successful execution of flood policies in Bangladesh (Johnson et al. 2008).

Coordination and Management

Flood risk management in Bangladesh is centralized and follows a command and control approach. The two leading ministries (MOWR and MOFDM) are responsible for the implementation of flood control projects as well as relief and response works during and after flooding events. But climate change and its related issues are only dealt with by MOEF. There are other institutions, which are directly and indirectly involved in flood management. This large institutional involvement lacks coordination and creates conflict of interests among the institutions. Zimmermann et al. (2010) argue that there is no coordination between GOB and donors for risk reduction and preparedness. Policy is still focused on emergency response. GOB also states that harmonization among donors and regional coordination is not still institutionalized. Furthermore, international and national development organizations implement their own DRR action plan in many different ways. It is well acknowledged that DRR and adaptation to climate change is location specific. But surprisingly, the local government of Bangladesh has no specific involvement in flood risk reduction except emergency management. Even local governments of flood-prone areas have no budgetary allocations for immediate emergency response. Flood-prone communities also have no role in flood management.

Climate Change and Uncertainties

Climate change is acknowledged as one of the key flood drivers in global policies, and it poses a significant threat to flood-prone counties like Bangladesh. But very few policies, plans, and acts incorporate it to address future development challenges. GOB and other bilateral development agencies (World Bank, Danida, DFID, ADB, etc.) develop special plans where climate-induced flood risks receive special importance. Those plans provide guidance as well as formulate different programs to increase communities' adaptive capacity and resilience to reduce flooding vulnerability. However, the majority of the climate change projection scenarios have been derived from regional climate change models where the study of Agrawala et al. (2003) is widely cited in the literature related to CC in Bangladesh. Recently, the Climate Change Cell (CCC) of Bangladesh has generated new temperature and rainfall scenarios using another regional model – PRECIS (CCC 2009). But the results of this model are not used in BCCSAP, which is the national plan of Bangladesh for climate change adaptation and mitigation.

This first NAPA (2005) of Bangladesh adopted the findings of Agrawala et al. (2003) for changes in temperature but used a modified version for changes in precipitation. This modification was carried out on the judgment of the NAPA core team rather than any GCM modeling exercise (Ahmed 2006). Later, the same scenarios of NAPA 2005 were applied in BCCSAP (GOB 2008, 2009b). NAPA 2009 which uses the partial output of the PRECIS model for changes in temperature and the rest of the data (changes in precipitation and sea level rise) is taken from NAPA-2005. This inconsistency in climate change documents shows a high level of uncertainty, which in turn limits the potential accuracy of future flood projections under climate change. It may also cause difficulties for policy makers and planners when making decisions on risk reduction and adaptation to flooding. Moreover, India is going to implement a river-linking project to redirect the flow of the Brahmaputra and Ganges basin toward the south and eastern parts of India to irrigate drought-prone areas (Bandyopadhyay and Perveen 2003; Shukla and Asthana 2005; Rahman 2005). This might cause a significant impact on the future discharge and flow velocity of transboundary rivers, which is not taken into consideration when estimating future changes in flood regime (GOB 2009a).

Opportunities in Existing Flood Regulatory Frameworks

The existing flood policies in Bangladesh are designed for effective relief and response to flooding but also have provision to increase the capacity to cope with disasters. Existing policies only respond to flood season, whereas floods at other times can also have a serious impact on poor people's lives and livelihoods, contributing to increase future vulnerability. Therefore, apart from the effective and timely response to flooding, it is imperative to help affected communities to enhance their adaptive capacity to cope with flooding and preparing for the future (Mutasa 2010). Additionally, the current draft of the National Disaster Policy (2012), draft of the National Agriculture Policy (2011), and new NPDM (2010) merely emphasize access and availability of resources in order to ensure sustainable livelihoods to create a "buffer" against flooding. Moreover, these policy frameworks still consider flooding along with other disasters as a crisis management rather than long-term planning.

The GOB acknowledges CC as a catalyst for future extreme flooding and has accordingly placed emphasis on flood risk reduction to increase the people's adaptive capacity as well as their resilience (GOB 2009a, b). NAPA and BCCSAP, as a part of medium-term and long-term climate change planning, highlight different flood risk management and reduction strategies including risk sharing such as insurance mechanism for the future. Additionally, these strategies adopt capacity-building programs for vulnerable communities and institutions and also "research and knowledge management" to assess the scale and impact of CC on the national economy for future informed planning. As a part of integrated disaster management, it incorporates the strengthening of community-based programs, a component which is missing in other flood-related policy frameworks. Moreover, it highlights the importance of increasing resilience of the poor and vulnerable "through development of community level adaptation, livelihood diversification, better access to service and social protection" (GOB 2009b, p. 27). Most importantly, BCCSAP has a specific annual allocation from the national budget to implement its programs and projects. There are few opportunities available in existing flood regulatory frameworks in Bangladesh, and now it depends on GOB to initiate and translate these opportunities into programs and projects in order to prepare the vulnerable communities to face future climate change-induced extreme flooding.

Conclusion

The above evaluation of flood regulatory frameworks provides an overview of the effectiveness of existing flood risk reduction, CCA, and resilience-related policies, plans, and strategies of Bangladesh. This study reveals significant gaps in policies/plans/acts to offer an effective mechanism to deal with climate change and future flooding across all sectors and their limited understanding of DRR and its linkages with CCA. It finds that there are policies/plans/acts that have recently incorporated climate change issues, but not all are finalized and no specific budgetary allocation and institutional framework for effective implementation of DRR and CCA activities has been initiated. Policies and regulations also fail to ensure the participation of vulnerable communities in flood risk planning and management. These planning policies are strongly in favor of flood-proofing urban areas and emphasize the significance of housing in the name of broad social and economic development.

As a result, the policy fails to accommodate the approach of social justice, which is the key principle of sustainable development to target the poor and most vulnerable, creating new forms of vulnerability. Moreover, there is no clear direction or guideline to mainstream DRR and CCA into the overall development of planning frameworks to enhance the resilience of vulnerable communities.

Appropriate and efficient implementation of flood regulatory frameworks and responsible institutions is seen as crucial in building the capacity of communities to resist flood risks and effects of CC, which might have the potential to reduce their vulnerabilities and increase their resilience to CC. Considering the gaps in existing regulatory frameworks, evidence-based people-centered policy formulations should be introduced to ensure the effective participation of all stakeholders including the active participation of vulnerable people for better flood management system in Bangladesh. Overall, "the overhauling of class relations" and narrowing the gaps between rich and poor through social transformation can provide a platform to ensure sustainable flood management under climate (Custers 1992). This is the prerequisite of all effective measures to reduce flood risks and vulnerabilities and to enhance people's resilience accordingly.

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Gender and Social Equity in Climate Change Adaptation in the Koshi Basin: An Analysis for Action

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Contents

Abstract

The impact of climate change is disproportionately higher on women, the poor, and socially disadvantaged groups. Yet, existing adaptation approaches and perspectives pay little attention to the special needs of these groups. Based on primary and secondary information collected from Nepal's Koshi Basin, this paper looks at differences in levels of multidimensional poverty between different social groups and tries to assess how these differences shape their respective

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capacities to adapt to climate change. It examines some of the challenges and constraints these different groups face in the adaptation process and the strategies they use to cope and adapt. Analysis reveals that women and marginalized social groups, especially Dalits and Muslims, experience deeper levels of multidimensional poverty and that, in turn, constrains their ability to adapt to climate change. Rural women are relatively more vulnerable to the adverse effects of climate change than men due to the complex socioeconomic, institutional norms and gender roles/relations that determine their access to and control over the physical, economic, human, and social resources required for adaptation. The results suggest that an interdisciplinary approach to climate change adaptation is needed that recognizes and addresses the special needs, roles, and constraints of women and disadvantaged groups. The organizational and policy processes as well as the capacity of women and disadvantaged groups needs to be enhanced to achieve better results or positive impacts of adaptation planning and implementation. A broader governance framework is suggested that would enhance the capacity of women and disadvantaged groups to respond proactively to climate change while at the same time working to change unequal power relations, institutions, and processes that have made these groups more vulnerable.

Keywords
Hindu Kush Himalayas • Gender • Social equity • Climate change • Vulnerability • Policy • Mountain • Adaptation framework • Koshi Basin

Introduction

Climate Change and the Need for Adaptation

Climate change is a global threat to people's well-being, especially to those with limited resources and livelihood options (Dankelman 2002; Denton 2002; Yamin et al. 2005; Mehta 2007; Brody et al. 2008; Lambrou and Nelson 2010; Alston 2013). The Hindu Kush-Himalayan (HKH) region is experiencing higher temperatures and increased variation in rain and snowfall. Although mountain people have always been exposed to droughts, floods, soil erosion, and changes in the crop cycle (Shrestha et al. 1999; Tsering et al. 2010), the intensity and frequency of such stress events has increased over recent decades. Appropriate adaptation is critical, particularly for the poor women and other socially marginalized groups who bear a disproportionately high burden of climate change impacts. These groups require special attention to facilitate inclusive and sustainable adaptation (Dankelman 2002; Mitchell et al. 2007; Mehta 2007; Neumayer and Plümper 2007; Nightingale 2009; WHO 2011). The degree of vulnerability of an individual or group to climate change depends on the capacity of that individual or group to adapt; adaptive capacity is in turn shaped by economic, physical, institutional, and social factors, including gender, that determine the access to and control over economic and social resources (Adger et al. 2009; Jones and Boyd 2011; Lambrou and Nelson 2010;

Nightingale 2009; WHO 2011). Understanding the context specific to gender and social issues that affect the abilities of different groups to respond to climate change is very important for the design and effective implementation of local adaptation plans and strategies in the HKH region. This chapter aims to contribute to this understanding based on findings from the Nepal's Koshi Basin.

While the need for better adaptation to climate variability and change has been recognized at policy level (GOI 2008; MOE 2011), the collection and analysis of data disaggregated by gender and social group has been limited, hence the social implications of climate change, climate policies, and other drivers of change in the Koshi Basin (Khadka 2013) are poorly understood. As climate change and gender studies globally show, vulnerability and adaptation to the adverse effects of climate change are gendered social and economic processes: men and women across different social, economic, and education levels, ages, and caste/ethnic identities experience and respond to the shocks and stresses of climate change in very different ways. Men and women with diverse identities have differential capacity to cope with and adapt to change (Brody et al. 2008; Jones and Boyd 2011; Lahiri-Dutt 2014; Mehta 2007; Mitchell et al. 2007; Plan Nepal 2012). Sound and socially responsive climate change adaptation policies and governance practices are an important means of reducing vulnerabilities and empowering men and women across different social identities.

This chapter focuses on the Nepal Koshi Basin and examines the following three issues: (a) how the intertwined economic, sociocultural institutions and gender roles operating in the Nepal's Koshi Basin condition the ability of different social groups to respond to climate change-related shocks and build their resilience, (b) to what extent has the current climate change policy in Nepal recognized gender and social vulnerability to the negative effects of climate change and developed measures to enhance the adaptive capacity of most disadvantaged groups for more equitable outcomes, and (c) what possible approaches can be used to integrate gender and social issues into climate change programs in the Basin.

This chapter has seven sections. The first three sections introduce the rationale and the conceptual framework for the study. The fourth section discusses methodology used to collect and analyze data on multidimensional poverty and gender inequalities in Nepal's Koshi Basin. The findings on the multidimensional poverty levels of different social groups, their perceptions on climate change, and some of their strategies for coping with and adapting to the change are presented in the fifth section. A review of Nepal's national policy on climate change adaption is presented in the next section, and the final section offers conclusions and a suggested framework for action.

Gender and Social Equity Perspectives in Climate Change Vulnerability and Adaptation Frameworks

Women, men, and members of diverse social groups experience climate vulnerability differently and have different levels of capacity to adapt (Denton 2002; Mehta 2007; Mitchell et al. 2007; Demetriades and Esplen 2008; Brody et al. 2008;

Nightingale 2009; Skinner 2011; Alston 2013). Members of poor and socially marginalized households and women suffer more than other social groups when faced with natural disasters, including climate change (Bern et al. 1993; Oxfam International 2005; Gautam et al. 2007; Neumayer and Plümper 2007; Mehta 2007). Often men have more access to information on climate changes, ideas for adaptation, control over decision-making mechanisms, productive assets, and social capital (Alston 2013; Mburu 2014).

Women can also be at higher risk of losing their life during climate-induced disasters (Bern et al. 1993; Oxfam International 2005; Sharmin and Islam 2013). During the Bangladesh cyclone in 1991, the mortality rate among females over the age of ten was three times higher than that among males (Bern et al. 1993) and three times as many women as men died in Indonesia and India in the 2004 Asian tsunami (Oxfam International 2005). The higher female death rate has been attributed to gender norms on what men or women should look like, do, or have (Oxfam International 2005; Neumayer and Plümper 2007; Sharmin and Islam 2013). For example, in rural Bangladesh, women are not allowed to leave their home without a male relative (Sharmin and Islam 2013) and are expected to wear a sari, which hampers running and swimming; thus they are less able to move rapidly to a safe place during a disaster (Neumayer and Plümper 2007). However, gender norms hindering women's ability to prepare for disasters and benefit from development can be changed through better legislation, policy, institutional practices and decision-making, and investment in gender-sensitive research and capacity-strengthening programs that empower women (Alston 2013; Björnberg and Hansson 2013; World Bank 2014).

The Intergovernmental Panel on Climate Change report (2001) documents the fact that inadequate access to resources such as income, skills, knowledge, and other assets contributes to the increased vulnerability of some groups to climate change. In addition, social perception, interplay of power, and structural biases built into some institutions and processes can result in unequal access of certain groups to decision-making and opportunities for improved livelihoods (Lama and Buchy 2002; World Bank and DFID 2006; Arora-Jonsson 2011; Alston 2013).

Building local people's "resilience," or their ability to adapt to the adverse effects of climate change, is a priority agenda of governments, non-governmental organizations, and development agencies in the HKH region (GOI 2008; MOE 2011; NDRC 2007). Adaptation is increasingly viewed as an essential social process for reducing vulnerability to the negative impacts of climate and other drivers of change (Adger 1999; Yamin et al. 2005; Demetriades and Esplen 2008; Nightingale 2009; Adger et al. 2009). As with vulnerability, the factors that shape and affect people's capacity to adapt are not limited to biophysical and economic dimensions; the gender, caste/ethnic, and class identities of members of a community also play an important role in their respective adaptive capacities (Demetriades and Esplen 2008; Adger et al. 2009; Nightingale 2009; Arora-Jonsson 2011; Onta and Resurreccion 2011; Jones and Boyd 2011). Power relations are particularly important in determining vulnerability and adaptive capacity in the Hindu Kush-Himalayan context, where the majority of rural people derive their livelihoods from agriculture, animal husbandry, seasonal migration, daily wage labor, and the provision of ecosystems service and goods. Especially in the Indian and Nepal regions of the Koshi Basin, the social relations based on gender, caste, and ethnicity are still strong, creating significant differences between and among men and women in terms of economic, political, and educational opportunities and influence in policy and rural development processes. Therefore, gender and social equity perspectives are critical to understanding differential vulnerability to climate change and to designing adaptation plans and programs that not only reduce the overall adverse impact of climate change but ensure that climate change does not deepen existing inequalities in the HKH in general and the Koshi Basin in particular.

The Need for an Interdisciplinary Approach

Dominant approaches to adaptation (Agrawala and Fankhauser 2008; Bala and Hossain 2013; Benioff et al. 1996) tend to be dominated by economic and biophysical perspectives. However, these perspectives do not adequately recognize differential vulnerability based on gender and social identity or the specific practical and strategic needs of women and economically and socially marginalized groups. Nor do these approaches recognize that these diverse groups have different levels of capacity and, thus, need differentiated approaches to adaptation (Nightingale 2009). This situation is reinforced by the prevailing lack of an interdisciplinary perspective that considers the linkages between adaptation to climate change and social and gender equality.

The failure of climate policies and adaptation programs to take social dimensions into account can have significant deleterious effects on women and other economically and socially marginalized groups. They also fail to use the intimate knowledge of local conditions that rural women and indigenous communities can contribute to climate adaptation processes (Nyong et al. 2007; Lambrou and Nelson 2010). Women and other marginalized groups hold indigenous knowledge of low-impact low-cost methods and coping strategies that can support development of resilient farming practices in response to climate change (Meinzen-Dick et al. 2011). For example, rural women in Sikkim, India, and Nepal have conserved ecologically sensitive areas in community-managed forests and private lands, as well as plants that were nearing extinction. They conserve local landraces of crop varieties through maintaining home gardens and the practice of seed exchange between communities (Karki and Gurung 2012; Dhakal 2012). This indicates how local natural resource management and farming practices can contribute to adaptation. Therefore an effective response to climate change requires a holistic and interdisciplinary approach that includes a sociocultural perspective and pays explicit attention to gender and social relations (Brody et al. 2008; Hannan 2009; Nightingale 2009; Lambrou and Nelson 2010; Arora-Jonsson 2011; Jones and Boyd 2011; Alston 2013; Björnberg and Hansson 2013; Lahiri-Dutt 2014). This study adopts this perspective and assesses the vulnerability and adaptive capacity of different social groups by gender, caste/ethnic identity, and poverty. A climate change adaptation framework for action is proposed that emphasizes the gender and social dimensions of the adaptation process and offers suggestions on how existing policy and institutional frameworks can take the social dimension into account in adaptation planning and implementation for achieving equitable social outcomes.

Study Area, Data Collection, and Social Diversity

This research is based on primary data collected from Nepal's Koshi Basin region using a survey for the quantitative data and collecting qualitative information through ten key informant interviews, six focus group discussions with women and men householders, and field observations in two districts. The Koshi Basin region occupies parts of India, Tibet/China, and Nepal and is one of the ten major river basins in the HKH region. Secondary data were obtained from a thorough review of the relevant literature from the HKH region and the Koshi Basin, including recent national statistics from Nepal and a review of Nepal's climate change, and social development policies.

Nepal's Koshi Basin is located between China and India. While the northern part of Nepal's Koshi Basin is inhabited mostly by ethnic groups speaking Tibeto-Burman languages and practicing Buddhism, in the southern part the Hindu influence on sociocultural practices is dominant.

Survey Methods

The survey was carried out in Nepal's Koshi Basin as part of a program to better understand and facilitate climate change adaptation implemented by the International Centre for Integrated Mountain Development (ICIMOD). Quantitative data were collected from a total of 5,383 households (62 % male informants and 38 % female) in 14 of the 26 districts in the Nepal part of the Koshi Basin (Fig. 1) between 2011 and 2012, using the poverty and vulnerability assessment (PVA) survey instrument (Gerlitz et al. 2014). Households were the basis for survey. Since men are generally considered the households heads, they tended to take on the respondent role in the survey. Hence, there were substantially more male respondents than female.

The recommended sample size was 384 households for each district. Household selection within districts was based on a multistage random sample with an equal probability sample of elements at all stages. The primary sampling units (PSUs) were village development committees (VDCs) and the ultimate sampling units (USUs) were households. To guarantee a good geographical coverage as well as the inclusion of the urban population, all VDCs in a district were divided into the categories "urban" (municipalities and district headquarters), "rural, quarter 1" (generally northwest), "rural, quarter 2" (generally northeast), "rural, quarter 3" (generally southwest), and "rural, quarter 4" (generally southeast) and listed. Initially, PSUs were selected randomly from each of the five lists. In all districts, one VDC was selected from the list of urban PSUs. The USUs were selected using random walk procedures (Gerlitz et al. forthcoming). The survey was carried out in

Fig. 1 Map of the Koshi Basin showing the study districts within the Nepal part

two parts, and the second part included more details and some additional questions; thus some of the results are based on responses from the second part of the survey only. The final numbers of respondents used in the analysis of individual questions were lower than the number of surveyed households, as households were excluded when data for a question was missing.

The Study Area Population

The Koshi Basin's inhabitants include men and women from a wide variety of caste/ethnic and religious groups. Women slightly outnumber men (50.5 % vs. 49.5 %); 82.3 % of the people in the region are Hindu, 13.3 % Buddhist, 1.5 % Christian, 1.2 % Muslim, and 1.7 % others (Field survey 2011, 2012). For the purposes of the survey, respondents were divided into broad ethnic/caste groups that reflect overall social advantages and disadvantages. These groups were the Janajatis/ethnic groups, or indigenous peoples, who traditionally have a special cultural association with forests, water, land, and other natural resources from which they earn their livelihoods (Sherpa 2012), the so-called "upper" caste Brahmins and Chhetris, the "lower" caste Dalits, and a diverse "middle" caste group. Among Janajatis, the Newars tend to be more advantaged (Gurung 2006); thus for the purposes of some analysis, Newars have been grouped together with the upper caste Brahmins and Chhetris, referred to as Brahmin/Chhetri/Newar (BCN).

Janajatis represented the single largest group (43.4 %), followed by BCNs (31.1 %), Dalits (15.8 %), "middle caste" groups (8.6 %), and Muslims (1.2 %). Although Muslim is a religious group, it is treated as a caste/ethnicity category in Nepal due to its social distinctiveness (Sharma 2014) and the need for greater attention to mainstream them as one of the important social groups in national development policies and practices (UNDP 2009). The "middle caste" groups in the sample were all from the three Tarai (plains or Madhes) districts and represent a fairly wide range in terms of their social and economic status. The proportion of Dalits in the surveyed areas was higher than in the national population (13.2 % according to the 2011 Census), and the proportion of "middle" caste groups and Muslims was lower.

By geographical region, the survey respondents are categorized into the caste/ethnic groups from tarai/plain areas (e.g., Tarai Brahmin/Chhetri, Tarai "Middle Castes", Tarai Janajati, Muslims, Tarai Dalits) and the caste/ethnic groups from the Hill/Mountain areas (e.g., Hill Brahmins, Chhetri, Newars, Hill/Mountain Janajati, and Hill Dalit).

Data Analysis

Data were analyzed at three levels. First, the multidimensional poverty across different social groups was analyzed using the Multidimensional Poverty Measure for the HKH region (MPM-HKH) (Gerlitz et al. forthcoming). This measure includes six dimensions in which well-being/deprivation can be assessed and a total of 15 indicators used to measure these six dimensions (Table 1). The indicators used to measure poverty or deprivation in each dimension were specific to the Hindu Kush-Himalayan region.

The second level of analysis involved an examination of gender-based social vulnerabilities with a focus on gendered access to resources and economic opportunities, gender roles, responsibilities, social norms, and their implications for women's adaptive capacity. The ways different social groups perceived climate

Table 1 MPM-HKH – poverty dimensions and indicators

Poverty dimensions	Indicators
Education	Literacy and education
Health	Illness, health care, and food consumption
Material well-being	Assets (TV, radio, telephone) and dwellings
Basic facilities	Electricity, drinking water, and sanitation
Social capital	Access to community decision-making and social networks
Physical accessibility	Access to markets, hospitals, a bus stop

change, its adverse effects, and their adaptive capacity were also examined. This, along with a review of Nepal's existing climate change policies, constituted a third level of analysis.

Results and Discussion

Multidimensional Poverty and Vulnerability by Social Group

Figure 2 shows the MPM-HKH and the poverty headcount for each of the nine major caste/ethnic discussed above. In terms of the incidence of multidimensional poverty (shown in red) and the Multidimensional Poverty Index value (shown in blue), the Tarai and Hill Dalits are significantly more deprived than all the other groups.

Nearly half or 48 % of Tarai Dalit households are multidimensionally poor, closely followed by the Hill Dalit with 31 % in poverty. Dalits from the Tarai and Hills also have the highest poverty index values (0.21 and 0.14 respectively), followed by the Muslims and Hill Janajati, both with index values of 0.11 or roughly half those of the Dalits.

The MPM-HKH also allows us to look at differences in the composition of poverty and in the importance of different dimensions of deprivation for different groups. Thus in Fig. 3 we see that for all the Tarai caste/ethnic groups, accessibility (shown in tan) is not a factor contributing to deprivation. Tarai Dalits and Tarai Brahmins benefit equally from the greater connectivity and road networks present in the plains areas. Similarly, all the hill/mountain groups suffer to some degree from the poorer connectivity and access to transportation in the mountainous regions.

Yet among the hill/mountain groups, those who face the greatest challenge in terms of physical accessibility are the Janajati – who often live on the higher slopes and more remote valleys. Although physical accessibility is not a big issue for Tarai Dalits or Muslims, these groups are highly deprived in terms of access to basic facilities such as sanitation, water and electricity, material well-being, education, and health. It is interesting to note that, while Nepal's Human Development Report, 2009, showed Muslims as having the lowest Human Development Index (0.401) measured in terms of life expectancy, education, and income, followed by all Dalits

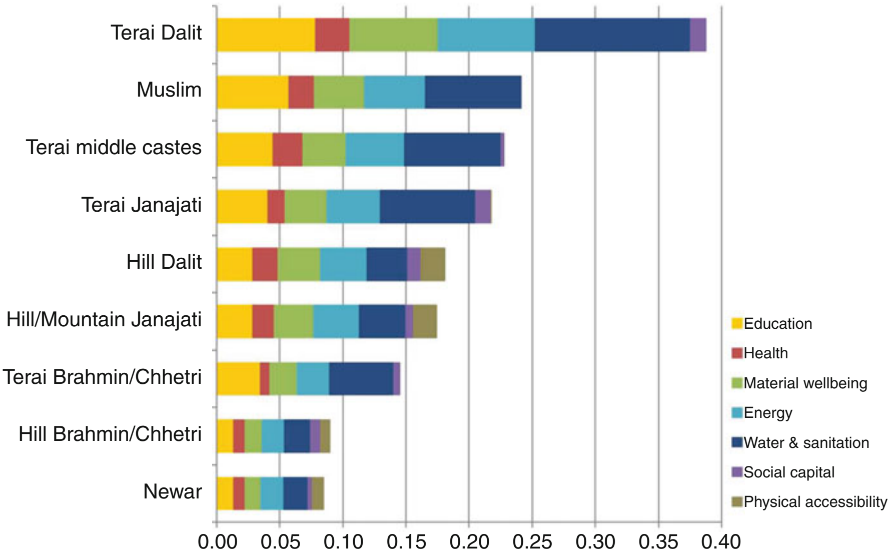

Fig. 2 MPM-HKH index value and headcount by social group

(0.424), the MPM-HKH shows the Muslims doing better than either the Hill or the Tarai Dalits. This is consistent with the most recent National Living Standard Survey in 2010/2011 that shows a significant drop in consumption poverty among the Muslims since the 2003/2004 survey.

The MPM-HKH in the Koshi Basin shown in Fig. 3 indicates that some groups within some communities could be potentially more vulnerable to climate change than others. For example, lack of social capital is a major constraint for Tarai and Hill Dalits and Muslims to cope with and adapt to the negative effects of climate change. Social capital helps people formulate livelihood strategies that enhance their ability to cope with extreme weather conditions as Dulal et al. (2010) point out. Membership in formal and informal institutions and opportunities to have voice and influence in decision-making in the institutions and networking with multiple stakeholders are some indicators of social capital (World Bank and DFID 2006; UNDP 2009). In the Nepal's Koshi Basin, Dalits and Muslims report greater difficulty in influencing the local decision-making processes than members of the Brahmin, Chhetri, Newar, Janajati, or Tarai "Middle Caste" groups (Fig. 4).

As shown in Fig. 4, different social groups differ in their perception of their ability to influence local- and higher-level decisions that affect them. In terms of higher-level decisions, households from all caste/ethnic groups felt they had little influence – though more BCN households felt they could influence such decisions than Dalit households (31 % and 18.1 % respectively). In the area of local-level decision-making, Muslim households showed the lowest levels of self-perceived influence: 34.9 % compared to 46.7 % for Dalits and 70.4 % for Brahmins and Chhetris.

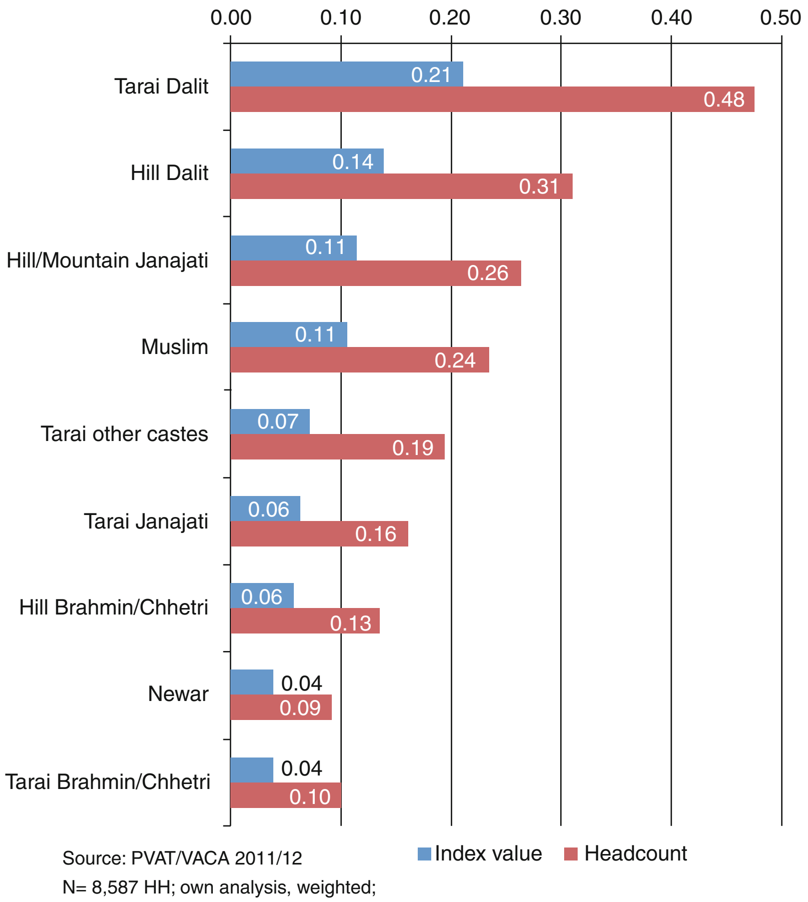

Fig. 3 MPM-HKH index value and absolute contribution of poverty dimensions by social group

One factor that is linked to the low levels of Dalit and Muslim social capital is their low level of education which restricts their access to information about climate change, adaptation ideas, and services that are communicated in texts. Low education levels coupled with low levels of social capital in turn reduce their ability to influence decision-making mechanisms related to climate change adaptation and reduce the likelihood that they will be represented by members of their own community when critical decisions are made. Dalit women are even more likely to be left out of communication and decision-making "loop" regarding climate change adaptation – unless climate change communication approaches make special efforts to respond to the additional barriers to participation they face as women. As McOmber et al. (2013) point out, women farmers' ability to adapt to climate change tends to be weaker in part because they are left out of many communication channels.

The high levels of health deprivation among Dalits and other marginalized households evident in quantitative data were also evident in field observations in

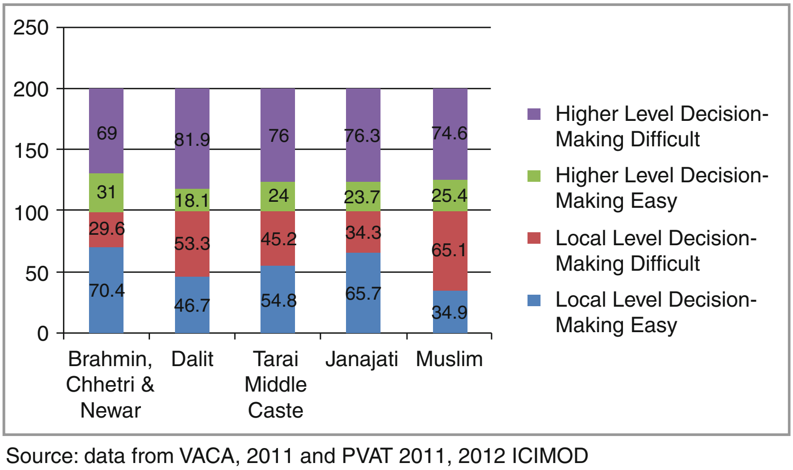

Fig. 4 Influence in decision-making process by social group (% response, $N = 5{,}378$) in the Koshi Basin, Nepal

flood- and drought-prone areas of the Koshi Basin where these groups were found to suffer more from illnesses such as typhoid, body swelling, diarrhea, and jaundice (Field note, July 2012). Although not specific to the Koshi Basin, case studies and reports from Nepal (Rai Paudyal 2008; Khadka 2010a; ANPFa 2011; DNF 2012) indicate that the majority of Dalits are landless or land poor. Many live in temporary houses and are in sharecropping relations that make them dependent on landowners.

Their houses tend to be flimsy and unable to withstand high winds or floods – another source of vulnerability to climate-induced hazards. Dalits are also more likely to live in disaster-prone areas such as sloping areas, riverbanks, and land susceptible to soil erosion or landslide (DNF 2012; Jones and Boyd 2011).

The above discussions indicate that socioeconomically marginalized social groups tend to be most vulnerable to the negative effects of climate change and have inadequate capacity to cope with and adapt to the negative impacts of climate change and climate-related hazards.

Gender-Based Social Vulnerability

Gendered Access to Productive Resources and Economic Opportunities

Resource availability and economic opportunities for women and men were analyzed on the basis of land ownership and involvement in different activities. The results are shown in Table 2. Fourteen percent of the surveyed households reported that women owned some land against 81.5 % for men. Men worked more in agriculture, livestock raising, fishery, and other economic activities, while women contributed more to the "care economy" through spending their time in cooking;

Table 2 Gendered access to resources and economic opportunities

Parameter	Gender	
	Women	Men
Agricultural land and cultivation		
% of households with agricultural land owned	14.0	81.55
Average no. of household members working on farm	1.7	1.5
Involvement in household work including looking after household members (% of women/men engaged in activity[a])		
Cooking	92.9	1.4
Fetching water	57.9	2.7
Collecting fuelwood	42.4	6.3
Seed purchase	16.1	51.1
Caring for children and the elderly	46.5	2.4
Involvement in cash income activities (%) of time		
Selling agriproducts in the market	16	34.7
Average no. of family members per household employed in paid work for 10 or more months	0.13	0.38
Migrants outside country (% of total)	12.0	88.0
Average no. of migrants per household (outside country)	0.02	0.32
Average annual remittances received per household from migrants within country (USD)[b]	14	118
Average annual remittances received per household from migrants outside country (USD)[b]	13	339

Source: Field survey 2011, 2012
[a]Excluding the percentage of labor done jointly by men and women
[b]1 USD = NRs 95

caring of children, the sick, and elderly; collecting water and fuelwood, food processing, and other chores traditionally classified as "domestic activities" or "housework." Nearly all women (93 %) were engaged in cooking meals compared to only 1 % of men. Men were more active in purchasing seed and selling agriproducts; women's roles focused more on collecting water and fuelwood. This finding is similar to observations by others in Nepal (Acharya and Bennett 1981; Regmi and Fawcett 2001; St. Clair 2003). There were also marked gender differences in income-earning opportunities. On average, more men had access to paid employment for 10 or more months (0.38 per household compared to 0.13 for women). This finding from the Koshi Basin survey is consistent with the 2001 and 2011 census data showing that men are seven times more likely to migrate to urban areas or abroad for work or study than women (Khadka 2013). In the Koshi Basin survey, 88 % of those migrating for employment were men, so women's contribution to remittances was correspondingly low. Households received an average value in cash and kind of USD 14 from women and USD 118 from men who had migrated for employment within the country and USD 13 from women and USD 339 from men who had migrated abroad.

Table 3 Time cost of collecting fuel and water (hours/day)

Social group	Collecting fuelwood		Fetching water	
	Men	Women	Men	Women
Brahmin, Chhetri, Newar	1.03	2.14	0.57	1.16
Dalit	1.04	1.59	0.93	2.29
Tarai middle caste	0.32	2.31	0.65	2.11
Janajati	1.12	2.08	1.02	1.52
Muslim	0.40	1.45	0.45	1.33
Average	0.78	1.91	0.72	2.28

Source: Field survey 2011, 2012

Time Spent Collecting Fuel and Water and Implications for Gender Vulnerability

Table 3 shows the average time spent by men and women from different social groups in collecting fuel and water. Women spent an average of 4.19 h per day collecting water and fuelwood and men 1.5 h. The additional time spent by women on these activities may limit their ability to participate in cash income-generating activities, community leadership, or taking advantage of economic opportunities created as a result of climate change. In the Koshi Basin, as elsewhere in most of South Asia, women have the primary responsibility for fetching water, and this has a number of implications for them in terms of time and work burden. During prolonged drought, women must often travel long distances to alternative water sources when nearby springs dry up. The drying of springs due to climate change has led to increase in women's drudgery (Dixit et al. 2009). Women's workload also increases in post-disaster situations because the usual sources of water, fodder, and fuelwood are disrupted, forcing them to walk longer distances to secure these essential resources for their families (Mehta 2007; Swarup et al. 2011). Moreover, gathering fuel and water from very fragile, harsh (too cold or too hot), sloping, remote, and difficult terrain and socially insecure areas also increases the vulnerability of women and girls when these resources are disrupted by the impacts of climate change.

Social Institutions/Norms: Implications for Adaptive Capacity

A number of social norms or institutions restrict women's access to services, resources, and decision-making. For example, the social institution of *purdah* or veiling (practiced mostly among the Madhesi Brahmin, Chhetri, and "middle" castes and Muslim women) is strong in the Tarai plain districts of the Nepal's Koshi Basin and presents a major obstacle to women's full economic and political participation. In these areas women's mobility, social interactions, and reproductive decisions are largely controlled by male household members. In focus group discussions, women would only speak out when no men were present in the group. In all groups in the Tarai and in higher-status groups throughout the Basin, there is a social stigma attached to women who work for others – especially for wages – and women are expected to have male protection when they move outside the home. Thus Tarai women in households, where men have migrated, rely heavily on the remittances sent by their husbands or sons (field notes, July 2012). Although Dalit women suffer less from restricted mobility, they are generally forced by economic need to carry out low-status wage labor. They also tend to experience more gender-based violence (Ghimire 2008; Gurung et al. 2014). In migrant households in the Hill districts of the Nepal Koshi Basin, women don't control the use of remittances; instead their husbands instruct them from abroad over phone on where and how to spend the funds they have sent (Adhikari and Hobley 2011).

Other social institutions such as early age of marriage, dowry, ideas of women's impurity during menses and after childbirth, and other forms of gender discrimination such as violence against women, son preference, and the tradition of patrilineal land inheritance in the Koshi Basin also reduce women's ability to adapt to climate-related stresses. Early marriage limits girls' ability to complete their education and their chances to gain some degree of economic empowerment.

The prevalence of the patrilineal system of inheritance where landed property transfers from father to sons within a family further disadvantages women who have limited rights to own family land and other properties (Gurung et al. 2014). Land ownership by women is an indicator of their empowerment and ability to influence household food security and well-being (Allendorf 2007). In the Nepalese context, being a landowner confers social prestige and increases a person's ability to influence household and community decisions (Allendorf 2007; Rai Paudyal 2008). Women's limited ownership of land thus has implications for their ability to respond to climate change impacts. For example, since most women do not own the land they work, they tend to lack the authority to decide on changes in land-use practice and cropping system as an adaptation strategy.

Women's membership in local water user associations (WUAs) and other community organizations and their meaningful participation in decision-making about natural resources are very minimal in the Koshi Basin. Interviews with Dalit women and Muslim women indicate that their voice on water access and distribution is rarely heard in water user committee meetings because men, mostly non-Dalits, who are in the major decision-making positions (e.g., chair person, secretary, advisor) are more interested in using the water for irrigation than for drinking and sanitation (Field note, July 2012).

A study from Sarlahi district of the Koshi Basin indicates that more girls than boys under age 5 died from flood-related disaster. This is probably related to the strong son preference throughout the Koshi Basin that leads to favoring boys when hard choices are made in the allocation of resources (Bartlett 2008 in WHO 2011, p. 12).

These findings suggest that social institutions/norms along with gender inequalities in access to and control over productive resources and livelihoods options affect the adaptive capacity of women, especially the socially and economically disadvantaged women in the Koshi Basin.

Climate Change and Socially Differentiated Impacts

People's Perceptions of Climate Change and Livelihood Problems

People living in the Koshi Basin are experiencing the impacts of climate change. Around 84 % of respondents had perceived some type of change in the environment (climate) in the past 10 years (Fig. 5). They reported an increase of events such as drought, flood, erratic rainfall, hailstorms, landslides, fire, high temperatures, poor seed development, livestock disease, insect attacks, and crop pests. More than 80 % of the households interviewed mentioned that the temperature and rainfall patterns had changed over the previous decade; 60 % said that the hot season had become hotter and 35 % that the cold season had become colder. Changes reported in precipitation included more erratic rainfall, fewer rainy days, precipitation coming later in the season, decreased summer precipitation, and decreased annual rainfall. These perceptions are consistent with the findings of other climate change research in the study area (Sharma et al. 2009; Mandal et al. 2013).

People in the study area are also experiencing a variety of interconnected environmental, social, and economic problems and challenges that have negative effects on their livelihoods (Table 4). The kinds of problems perceived differed somewhat between caste/ethnic groups; 52 % of non-Dalit households reported experiencing environmental problems as a significant issue over the past decade, compared to 43 % of Dalit and 33 % of Muslim households. This is probably because non-Dalit households are more likely to farm their own land, and thus, changes in seasonal cycles of rainfall and temperature may have a more direct impact on their livelihoods. For Muslims and Dalits, social problems were more prominent with 58 % of the Muslim and 45 % of the Dalit households reporting social problems compared to 38 % of the non-Dalit households. Economic problems were reported by a roughly the same percentage of households in all groups (9 % of Muslims, 10 % of Dalits, and 7 % of non-Dalits). This may be linked to the higher dependency of Dalit and Muslim household on agricultural wage labor to sustain their livelihoods. Overall economic factors appeared less problematic than environmental or social problems for all respondents, regardless of gender or caste/ethnicity.

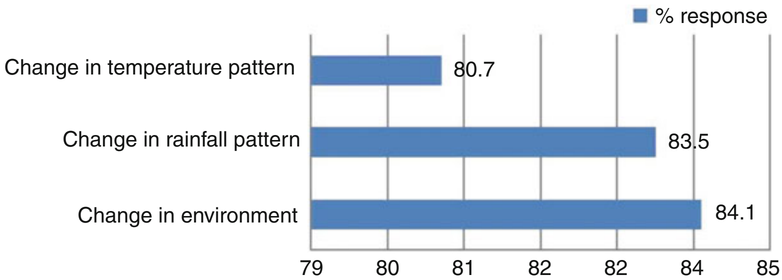

Fig. 5 Perceived change over the past decade

Table 4 Problems noted by respondents during the last decade

Social group	Type of problem			
	Environment[a]	Social[b]	Economic[c]	Other
	% of respondents noting problems			
Non-Dalit[d]	52.4	38.2	7.4	1.9
Dalit	42.9	46.0	10.1	1.0
Muslim	32.6	57.6	9.2	0.7

Source: Field survey 2011, 2012

[a]Drought, flood, erratic rainfall, frost, hail, snow, landslide/erosion, earthquake, strong wind, high temperature, low temperature, fire, insect attack, crop pests, poor seeds, irrigation problems, wildlife related shocks, and others

[b]Theft, bandhs (closures), local and national conflict, personal violence, intimidation, imprisonment, gender-based violence, and others

[c]Labor shortages, low market prices for crops/livestock, poor market access, lack of fertilizer or too expensive, family sickness, death of family member, debt, taxes, unemployment, loss of house, failure of business, corruption, and others

[d]Excluding Muslims

Gender-Specific Impacts of Climate Change

A number of aspects of climate change experienced in the Koshi Basin have gender-specific impacts. One of these is the increased shortage of water. The number of households in the Nepal part of the Koshi Basin who fetch water from rivers or streams and open wells has increased over the past decade, whereas the number with access to a covered well as the main source of water for domestic use went down by 60 % (Khadka 2013). This is because of the disappearance of underground water and lack of water management for recharging the ground water. As noted earlier, women and girls do most of the work to fetch water for cooking, cleaning, washing, bathing, and drinking (for people and animals) in the Koshi Basin. Reduced access to covered wells means that women and girls have to walk farther to fetch water, which increases their workload, and collecting from open sources means they (and their families) are more exposed to unsafe water. In focus group discussions, women mentioned that they have to walk at least 1 hour on average to fetch a bucket of water. A recent study by Plan Nepal (2012, p. 24) suggests that girls are most likely to be affected by climate change in some of the Koshi Basin districts because when local water and forest resources are depleted, they are the ones who have to travel long distances to collect fuelwood, fodder, and water.

The shortage of water has direct implications for overall family health and sanitation. Children with limited access to toilets and sanitation suffer more from diarrhea (Bose 2009). Only 67 % of households surveyed had toilets. Respondents in the Tarai districts reported that they preferred to practice open defecation and didn't want to build or use toilets because of the lack of water. The percentage of households owning a toilet was lower for all Tarai groups (Brahmin/Chhetri 56 %, Janajati 47.9 %, "middle castes" 36 %, Dalits 22.2 %) than for all hill groups (Brahmin/Chhetri 85 %, Janajati 68 %, Dalits 68 %). This finding corroborates other studies (MOHP 2011). Girls skip school when they are menstruating because of poor sanitation facilities at school. Also, the number of days out of school has increased for girls by up to 65 % in both the hills and the Tarai due to climate-induced disasters (Plan Nepal 2012, p. 32).

Floods trigger human disease, social insecurity, and mental stress. It was apparent from focus group discussions with women in flood-affected communities that many infants suffered pneumonia and mothers experienced joint aches and body swelling after giving birth in houses which are not flood resistant and have cold and wet floors (field note July 2012). Women also reported experiencing gender-based violence during water hazard events. Sexual harassment, attempted rape, and sexual abuse against women and girls are common in the temporary shelters where flood-affected people must reside (Acharya and Aryal 2008).

Key informants specifically mentioned the way that the flood in 2008 had affected food security and gender roles. Poor farmers used to rely on farm work from their landowners. When the fields turned into barren land covered with sand, the marginal farmers lost an important livelihood source and even the large landlords suffered losses. Young men who used to migrate for work in India or Nepal in the agricultural off-season have now begun to migrate for longer-term work, especially to the Gulf countries, leaving women, the elderly, and children behind. The women left behind reported encountering abuse and harassment from relatives when they had to take over previously male responsibilities, such as going to district headquarters for extension services (UN RCHCO 2013). Men's outmigration has also increased women's already heavy workloads, as they have to carry out livelihood activities and participate in social activities previously done by men in addition to their household and farm activities (Adhikari and Hobley 2011).

In Sindhuli district winter rains were reported as reduced, absent, or coming at the wrong time; hence most families have given up planting millet, barley, and buckwheat (Plan Nepal 2012), which are sources of iron and other nutrients that help overcome malnutrition and anemia problems that many women and children in Nepal experience (MOHP et al. 2012). Similarly, farmers in Makwanpur district have stopped planting mustard, millet, and pumpkin that used to grow abundantly a few years ago due to the reported decline in productivity of these crops which could be related to lack of water (Plan Nepal 2012). Selling mustard and vegetables in local markets is one of the sources of subsistence income for rural women in the Nepal Koshi Basin. Reduced production of these products has meant a loss of income-generating opportunities for women.

Differential Coping Capacity

Respondents were asked what they had done to cope with the environmental, social, and economic problems they had encountered over the last decade; the results are shown in Table 5. Men and women in all groups reported that they had borrowed money from relatives, friends, local money lenders, and village/cooperative funds. Overall, men were more likely to borrow money than women, but women were more likely to borrow from cooperatives or village funds. Cooperatives or village funds were also more important for BCN and Janajati people than for Dalit, Tarai "middle castes," or Muslim groups. This could be a reflection of higher membership

Table 5 Ways of coping with social, environmental, and economic problems

Common coping strategies	Social group by caste/ethnicity % response ($N = 2{,}299$)					Social group by gender % response ($N = 2{,}299$)		
	BCN[a]	Dalit	TMC[b]	Janajati	Muslim	Women	Men	Overall
Borrowed money from relatives	32.7	41.2	46.2	30.3	20.7	33.8	35.6	34.8
Borrowed money from moneylender	24.4	37.7	30.8	30.3	27.6	26.6	31.8	29.5
Borrowed money from friends	22.3	26.7	38.7	20.6	24.1	22.2	26.7	24.7
Borrowed money from cooperative/ village fund	23.2	11.9	7.8	16.9	6.9	18.4	15.4	16.7
Borrowed money from bank	8.8	8.8	12.5	4.9	24.1	7.8	8.2	8.0
Bought food on credit	15.9	19.2	10.2	19.1	17.2	17.9	15.9	16.7
Sold livestock and jewelry	18.0	9.1	11.0	20.0	0	14.5	17.6	16.3
Spent savings on food	15.9	8.2	6.7	9.6	17.2	10.0	11.8	11.0
Reduced number of meals	1.8	3.8	0.6	4.3	0	3.2	2.5	2.8

Source: Field survey 2012
[a]Brahmin, Chhetri, Newar
[b]Tarai middle castes

in community level financial institutions among these groups, but this needs further research. For most groups except Muslims and Tarai "middle castes," borrowing money from banks was generally less important than borrowing from other sources. Selling livestock or jewelry was an important strategy for BCN and Janajati groups but less or not at all for Dalit, Muslim, and Tarai "middle caste" people. It was also more important for men than for women. Muslim and BCN groups also used their savings to buy food.

The results show that for households in the study area with such assets, using their financial and physical capital is an important strategy for coping with the impacts of climate change. Borrowing money, selling livestock, and spending household savings on food however have the potential to increase the level of vulnerability. Building people's resilience – that is, their ability to adapt positively rather than just cope with or survive the impacts of climate change – is the goal of climate change policies and programs. In the following section, some examples of people's resilience are discussed.

People's Resilience

People in the Nepal part of the Koshi Basin have developed some resilience to adapt to climate change. Villagers in Maunabudhuk, Dhankuta district, have continued to build traditional multipurpose ponds close to their homes to harvest rainwater (ISET 2009). Water can remain in these ponds for more than 4 months and is used for livestock and irrigating fruit trees. Farmers have shifted their production from cereals to cardamom that requires less water but fetches a higher price than cereals (ibid).

The indigenous farming practices of farmers in Nepal are another example of community resilience. Intercropping with several crops is a commonly used strategy in the mid-hills of Nepal, including the Koshi Basin districts. Farmers plant millet and soybean in the same plot and intercrop climbing beans in maize fields to fix nitrogen and act as natural fertilizer (Jansen 2010). Soybean has also been planted along the bunds of paddy fields to prevent erosion and provide additional revenue. In some villages, farmers also have traditionally planted three different crops (lentil, black bean, and sesame) on the same land. The crops are alternated each year to minimize pests and diseases and improve soil fertility and nutrition (ibid). Farmers practice mulching or cover crops to conserve soil moisture. They introduce legumes or nitrogen-fixing crops into the major crops such as maize or wheat. Legumes provide additional income and protein-rich food in case the major crop fails or is lost (Shrestha et al. 2014).

To combat crop diseases, farmers resort to indigenous pest management practices such as bio-pesticides, scattering ash or cow urine, crop rotation, and intercropping (Jansen 2010; Shrestha et al. 2014). In response to erratic precipitation, farmers have adjusted the agricultural calendar by delaying or moving forward the time of sowing and harvesting their crops (Jansen 2010). Farmers also have practiced income generation activities that are low-cost and less labor intensive and cannot be affected by the adverse effects of climate change. For example, they are involved in value chains of high-value products and services, such as non-timber forest products, medicinal and aromatic plants, indigenous honeybees, and ecotourism (Choudhary et al. 2011; Pratap et al. 2012). As case studies reveal (Mitchell et al. 2007; Karki and Gurung 2012; Shrestha et al. 2014), women farmers are actively involved in the promotion of homestead gardens, water ponds and tree conservation in ecologically sensitive areas, agroforestry, off-seasonal vegetables, alternative energy technologies (biogas, improved cooking stoves), and agricultural soil management.

Policy Frameworks and Responses to Climate Change

Mainstream policies on climate change tend to consider women as a vulnerable group rather than recognizing them as an important resource or as agents of change for development. So far such policies have tended to mention the need to consider women's participation rather than specifying measures to achieve it. For example, although Nepal's National Adaptation Programme of Action (MOE 2010) recognizes women's roles in household activities and the possibility that adverse effects of climate change might increase their vulnerability, it does not have any specific strategies for gender inclusion (Kumar 2011; Mainlay and Tan 2012) or for overcoming the social vulnerability that constrains women – as well as the poor and socially marginalized – from improving their adaptive capacities. The NAPA (MOE 2010) framework has six broad strategic elements (agriculture and food security, water resources and energy, forests and biodiversity, public health, urban settlement and infrastructure, and climate-induced disaster), but none mentions gender or social identity as an important issue in the adaptation process. The nine projects prioritized for climate change adaptation lack clear mechanisms for the inclusion of women and other disadvantaged groups and strengthening their adaptive capacity, networking, and decision-making power over the use and management of local natural resources (Mainlay and Tan 2012).

Similarly, although Section 8.4.2 of Nepal's Climate Change Policy (2011) states the importance of "ensuring the participation of poor people, Dalits, marginalized indigenous communities, women, children, and youth in the implementation of climate adaptation and climate change related programmes" (see MOE 2011, p. 7), the policy has no analysis of gender, social exclusion/inclusion, or the indigenous knowledge and skills that many caste/ethnic groups hold in terms of natural resource management and local livelihoods. Hence there is little conviction behind the stated commitments and no empirical evidence upon which to base necessary governance and policy measures to ensure women and disadvantaged people enjoy their right to participate in and benefit from adaptation programs and processes. Many studies of Nepali society have identified the persistent inequalities and the influence of social elites and men in local decision-making and participation processes (Lama and Buchy 2002; Nightingale 2002, 2006). The challenges to making development equitable and sustainable in the natural resource sector are well known. Yet Climate Change Policy and related governance structures are blind to social outcomes in the sense that they lack specific implementable provisions that can be monitored to ensure participation of women, the poor, and socially marginalized in decision-making and their access to climate change funds. There are no clear mechanisms to ensure that members of excluded groups have equitable access to these and other benefits that climate change adaptation and mitigation strategies would generate at all levels. Nor have any measures been put in place to restructure institutional practices and decision-making processes or to build the necessary capacity needed to implement climate change policies and programs in equitable and gender-inclusive ways.

Strengthening the knowledge and capacity of the government and other stakeholders, including the private sector and farmers, on climate change and its impacts on ecosystem services, the hydrological cycle, and people's livelihoods are most critical elements of climate change adaptation strategies (Tsering et al. 2010; Bartlett et al. 2010; Tiwari et al. 2014). Adaptive capacity-strengthening actions can include not only extension and training but also research and assessment, climate-sensitive planning, policy change, implementation, and monitoring (Tsering et al. 2010). Although both the NAPA and the Climate Change Policy mention the importance of capacity building, neither of these policy instruments gives much emphasis to specific capacity-building actions. They pay even less attention to strategies to transform the social, governance, and institutional structures that mediate responses to climate change.

Both the Climate Change Policy 2011 (MoE 2011) and the NAPA 2010 (MoE 2010) call for at least 80 % of financial resources for climate change adaptation to be available at community level to fund local-level adaptation activities. Yet the policies lack the overall governance structure and specific operational measures needed to ensure that the poor, ethnic/caste minorities, women, and other traditionally marginalized social groups have access to these funds. There are also no specific provisions to ensure that the fund would not be used in ways that could actually harm these groups. Tiwari et al. (2014) also note that there is a gap in institutional arrangements and capacity to effectively implement the Climate Change Policy provision requiring that 80 % of the climate change budget be spent on local level adaptation programs benefitting the poor and other marginalized social groups. Critics (Ojha 2011) point out that the governance institutions see communities as passive beneficiaries rather than active partners in development, and this also undermines the capacity of men and women natural resource users to develop adaptation measures appropriate to their needs.

Researchers have noted that communities have adapted to climate variability and other changes for many years, and, accordingly, their indigenous knowledge can be critical for climate change adaptation processes (Yamin et al. 2005; Nyong et al. 2007; Eriksen et al. 2011). From a gender perspective, men and women often have different knowledge about biodiversity resources and their sustainable use (Khadka and Verma 2012). All these sources of local knowledge are relevant for the climate adaptation process and need to be integrated into adaptation strategies. At present, however, this understanding is missing in Nepal's climate change adaptation strategies and climate policy. These policies tend to be guided by a purely biophysical and economic perspective and do not take into account the persistent sociocultural and structural inequalities in Nepali society when defining vulnerability and adaptation measures. Inclusion of social and gender issues and approaches in policy frameworks needs to be part of the policy process (Keeley and Scoones 2003). More effort is needed to develop local gender and social analysis capacity, to include women and other socially excluded groups in higher-level decision-making positions and policy making, and to ensure that social/gender expertise and financial resources are available for assessing vulnerability and adaptation at different scales so that Climate Change Policy processes can be made more gender inclusive and responsive to the needs of women and the most vulnerable social groups (Nightingale 2009; Khadka 2010b; Brown 2011; Nellemann et al. 2011; Lahiri-Dutt 2014).

Conclusion

This chapter shows how different social groups, including women, experience different levels of poverty and vulnerability to climate change impacts, face different challenges and constraints in adaptation, and have different resources with which to respond. Making adaptation more inclusive and sustainable requires an interdisciplinary approach to data collection and analysis that complements natural science research with approaches from social science that are able to bring in the perspectives and priorities of diverse local groups. It also requires more accountable governance systems that not only recognize varied levels of adaptive capacity among citizens but are committed to and capable of responding appropriately to reduce preexisting disparities. Compared to men from the dominant BCN group, Dalit and Muslim men and women – and indeed, women from all groups in the study area – are relatively more vulnerable to climate change. They are in a weak position to prepare for and cope with the negative impacts of climate change. Yet, despite their disadvantaged social and economic positions and greater exposure to the shocks and stresses caused by climate change, these groups have developed creative adaptation strategies that need greater recognition.

Nepal's NAPA (MOE 2010) and the Climate Change Policy (MOE 2010), however, are not sufficiently sensitive to gender and social equity. They lack provisions and institutional measures that could help empower women and other disadvantaged groups to participate in and benefit from climate change adaptation program and policy processes at all levels.

Recommendations for Action

An appropriate analytical and governance framework is required to mainstream social and gender dimensions into adaptation policies and strategies. Development of such a framework is beyond the scope of this paper, but we suggest the following elements to stimulate critical thinking.

- To better understand the complexity of climate change vulnerability and adaptation from the perspective of gender relations and across different castes/ethnicities, ages, classes, and locations, **complement natural science methods and frameworks with gender analysis and social science approaches**.
- **Recognize** the differential impacts of climate change on women and men and socially marginalized groups, the different levels of challenges and barriers that they experience, and their different capacity to adapt; and address their specific needs and priorities.
- **Integrate** gender and social dimensions into climate change policies and strategies including adaptation and mitigation; food security and agriculture; health, water, and sanitation; forestry; disaster-risk reduction; energy and technologies; and infrastructure.
- **Strengthen** the capacity of the government and non-state actors to better understand the social and gender dimensions of vulnerability to climate change. A first step in developing this understanding is to **insist on the collection, analysis, and reporting of gender and socially disaggregated data** and to use the knowledge generated as the basis for policy and program development. It is also important that disaggregated data are used to monitor outcomes

for different groups so that continuing or increasing disparities can be identified and addressed.

- **Change governance systems to enhance the access and entitlement of rural women and socially marginalized groups** to natural, financial, and social resources, including land, water, forest, and biodiversity, as well as health care, technology, training, education, and information, to improve their capacity to adapt to climate change.
- **Recognize that everywhere local people who work on the land and have deep contextual knowledge of the management of local natural resources are an important resource** in developing positive responses to the challenges of climate change. It is especially important not to overlook the knowledge of rural women and indigenous peoples.
- **Facilitate** access to information, knowledge, and gender and culturally appropriate technologies to make adaptation more successful and more equitable. Make sure that this knowledge is communicated using a variety of channels including those that can reach nonliterate groups.
- **Pay attention to governance structures for climate change adaptation**. Make specific provisions to ensure that women and socially marginalized groups can participate meaningfully in local and national adaptation planning, including the process of developing National Adaptation Programmes of Action (NAPAs). The accountability to ensure that funds meant to assist these vulnerable groups actually reach them must be clearly laid out and monitored.

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Gender, Governance, and Climate Change Adaptation

Melissa Nursey-Bray

Contents

Abstract

This chapter attempts to highlight the role that gender plays in the context of climate change adaptation. It uses a discourse analysis approach to comparatively present a review of the role gender plays in climate change adaptation. Currently, two discourse storylines dominate the exploration of gender and climate change. One tells a story about women being disproportionately impacted by climate change and constructs them as ongoing victims. The other storyline explores the role women play in building adaptation and simultaneously presents women as both being more resilient and having more agency in these contexts. Applying a gender lens to governance could include enhancing the role of existing communities of practice. This chapter attempts to provide a detailed review of and means by which to understand and present how climate change and climate change adaptation is driven

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by gender and the implications of this for ongoing adaptive governance. This chapter adds to gender analyses by considering the role of communities of practice arguing that their deliberate utilization can enable gender to be productively rather than negatively utilized to build robust, socially just, and innovative adaptation regimes.

Keywords
Gender • Climate change • Adaptation • Communities of practice

Introduction

Climate change is an issue that is affecting human societies and ecosystems on a global scale, albeit in variable ways at localized levels (Adger and Kelly 1999). Gender is important in trying to understand climate change impacts and societal responses to it. Gender is often at the heart of power and knowledge interactions but is as yet, understudied: "Whereas the concepts of class, poverty and race make regular appearances in social scientific analyses of global climate change, the same cannot be said for gender" (MacGregor 2010).

Further, it is often difficult to disentangle the role of gender from all the other impacts because as Terry (2009) notes climate change does not occur in a vacuum, but in the context of a multitude of other risks, including globalization conflict, health issues such as HIV/AIDS, and poverty. "Climate change is not gender neutral. Studies reveal that women and men's decisions differ along risk taking lines, use and type of coping strategies, adaptability, and advice taking and information seeking behaviours. Much of this has to do with existing gender roles and inequalities (Dankelman et al. 2008). The effects of climate change, including disaster and emergency situations, can magnify these and create new inequities and vulnerabilities" (Quinn 2009, Cannon 2002).

How societies deal with and adapt to its impacts and, within that, how gender will affect and be affected by impacts and response to climate change is the concern of this chapter. Currently, many studies focus on the negative impacts of climate change on women and specifically women in the developing world who tend to be poorer and likely to be disproportionately affected by climate change (FAO 2011). This chapter builds on this work and presents two key discourse storylines around gender and climate change which are catalyzed around (i) impacts and (ii) adaptation. The chapter argues that a gender lens can be built on in addressing impacts and building adaptation to climate change, via communities of practice which play a role in building local and adaptive governance regimes. The chapter concludes with a presentation of some key communities of practice and their activities in this context.

Method

Using the issue of gender as the focus, this chapter utilizes historical documents and discourse analysis to examine the way in which gender is discussed and then the implications of this for climate and gender policy. In this chapter "gender" refers to the socially constructed norms, roles, and relations that a given society considers appropriate for men and women. Gender determines what is expected, permitted, and valued in a woman or a man in a determined context (Alston 2013; Nelson 2011; WHO 2010).

Discourse analysis is a tool that assists in understanding the variations and constructions in and around gender. This is partly because the use of discourse helps the understanding of different actors' perspectives, in turn stimulating a fuller understanding of how individuals engage within policy processes, an "engagement that is fundamentally communicative and hence discursive" (Rydin 2005, p. 77). Discourse analysis can also assist in linking different actors and power/knowledge regimes to impact on decision making (Feindt and Oels 2005). Understanding the role discourse plays is important because of "its capacity to reveal the role of language in politics, its capacity to reveal the embeddedness of language in practices and its capacity to answer 'how' questions and to illuminate mechanisms" (Hajer and Versteeg 2005, p. 175). It is also a method that offers the capacity to explore power and its correlative concept knowledge and how they play out in practice. To paraphrase Dingler (2005) but replacing nature with the notion of gender: "The discourse of *gender* is a discourse of power where the constellations of power determine the construction of *gender*." Gender and climate change are both innately and intensely imbued with "wicked" power relations that, when together, are worth exploring so as to better understand how to use those dynamics to resolve rather than constrain the key issues facing society today: "The study of discourse also allows one to see how a diversity of actors actively try to influence the definition of the problem" (Hajer and Versteeg 2005, p. 177). Finally, given the global reach of both gender and climate change, using discourse analysis can help us map at various scales the multiple trajectories and distribution of power within the climate change/gender domains (Keil and Debban 2005; Oels 2005).

After Hajer (1993), who typifies the ways in which language about a subject and the on-ground activities join together as a discourse coalition, the chapter reports on two major discourse storylines or coalitions that emerge out of the literature and practice around gender and climate change. A discourse coalition is defined as "the ensemble of a set of story lines, the actors that utters these story lines, and the practices that conform to these story lines, all organized around a discourse" (Hajer 1993, p. 47).

Results

As Okali and Naess (2013, p. 3) argue, "when gender is used by mainstream agencies to talk about women, two contrasting pictures of women emerge: either they lack agency and hence the ability to exploit opportunities (and as a consequence struggle to fulfil their responsibilities in difficult if not near impossible circumstances), or, as is especially the case to-day, they behave as resourceful providers and reliable entrepreneurs." An interrogation of the literature and case studies finds this is indeed the case but it is in fact embedded within a broader delineation of gender in the context of (i) impacts and (ii) adaptation. In the context of climate change, gender discourse around impacts tends to focus on women and on women in the developing worlds, whereas discourse around adaptation is more differentiated, examines the experience of both men and women, and often focuses on the role of women as agents of change and people to depend on.

Storyline One: Women Are Disproportionately Affected by Climate Change

Overall what emerges from a review of studies in this area is a driving discourse that asserts that even in developed countries, women are disproportionately impacted by climate change (FAO 2010). Specifically, gender-differentiated situations such as poverty will exacerbate the increasing impacts of climate change over time. For example, 70 % of the 1.3 billion people living in poverty are women and “Gender-related inequalities are pervasive in the developing world. Although women account for almost 80 % of the agricultural sector in Africa, they remain vulnerable and poor” (Denton 2002). Forty percent of the poorest household in urban areas are headed by women, and while women dominate the world’s food production (up to 80 % in some cases), they still own less than 10 % of the land. Where women’s socioeconomic status is greater, it is clear that they are more resilient to impacts (Neumayer and Plumper 2007).

In the instance of natural disasters, studies highlight that the stronger the disaster, the greater effect on the gender gap, especially as more often than not, natural disasters lower the life expectancy of women. For example, boys are often given preferential treatment in rescue efforts over women and girls, women are often in the home and thus less able to get out of the disaster zone. During cyclone disasters in Bangladesh in 1991, 90 % of rather 140,000 mortalities were women. In South Africa, women, especially poor women, are impacted by climate policies, but do not get the opportunity to be part of the decision-making process (Anneke et al. 2010). Women in Mexico find their livelihoods are affected by changes in climate (Beuchler 2009). In Malawi, exposure, sensitivities, and adaptation all vary between women and men, with men generally having more opportunities than women. This highlights the need for policies to build better access to and involvement in climate programs for women (Kakota et al. 2011).

Women will be more exposed in developing countries to greater health and mortality risks, including water contamination, malaria, heat exhaustion, increase in infectious diseases, scarcity of water, salinization of water, flooding, mortality as a result of extreme weather events, disruption through forced migration, impacts of incomes after extreme events, and issues cased by family- and household-related stress and injury, including suicide (WHO 2010; Kukarenko 2011). For example, nutritional status affects women’s ability to deal with climate change; in South and Southeast Asia 45–60 % of women at reproductive age are underweight and have nutritional deficiencies, which means, for example, that more women than men will tend to die during a sustained heat wave or during drought and food shortages. In Hurricane Katrina, most of the victims trapped in New Orleans were African-American women.

In Sri Lanka during the tsunami, men survival rate was higher due to the fact that boys, not girls, are traditionally taught how to swim and climb trees. In disasters women are also more likely to be at risk of assault and abuse and have to physically depend on others due to pregnancy (WHO 2010; Smyth 2009).

Gender norms will also often dominate how public space is to be used or how women are to appear in public. For example, as Wong (2012, p. 15) notes of floods in Bangladesh, "…warning information was transmitted by men to men in public spaces, but rarely communicated to the rest of the family, and as many women are not allowed to leave the house without a male relative, they perished waiting for their relatives to return home and take them to safe place." Nagel (2012) notes that mores of masculinity, and adherence to notions of war, and men's dominance in science and government also mean that women are disproportionately disadvantaged by the moral and ethical frameworks which guide their lives.

Enarson and Morrow (1998) in their book *The Gendered Terrain of Disaster* state that gender inequalities more than differences explain the disproportionate impact of disaster on women and girls. This gendered terrain of disaster is characterized by a number of features seen in Table 1 below.

Alston (2011) notes there are also many gendered impacts in developed countries, such as Australia, but in this case focuses on people living in rural areas. In summary she outlines impacts including increasing poverty, financial pressures, emotional stress and other impacts, difficulties in accessing employment on and of farms, social isolation, community decline, marital and intergenerational conflict, loss of access to services and resources, the loss of young people from the district, and the demand placed on older people to work past retirement to make ends meet (see Alston 2003, 2006, 2007, 2012; Cole and Mitchell 2011).

Table 1 Gendered terrain of disaster

Live below the poverty line
Rely upon state-supported social services
Lack savings, credit, insurance
Lack inheritance rights, land rights, control
Be unemployed or work in the informal economy
Be self-employed, home-based, contingent workers
Reside alone, be rearing children alone
Depend on functioning caregiving systems
Depend on public transportation, travel with dependents
Reside in public housing, mobile homes, rental housing informal settlements
Live at risk of assault, and abuse, be displaced by domestic violence shelter
Be responsible for others (family, kin, neighbors), as paid and unpaid caregivers
Physically depend on others due to late pregnancy, recent childbirth age chronic illness
Be living with disabilities and chronic illness
Be subject to male authority in the household regarding use of emergency assets and key decisions about evacuation and relocation

Storyline Two: Women Have Resilience and Sometimes Agency in Adaptation Contexts but Are Still Often Disadvantaged Within Adaptation Programs

Discourse around gender and adaptation is more nuanced. However, again, women emerge as the victims and, in this case, negatively impacted by adaptation efforts – even where agency is present. As a discourse storyline, there is a much greater differentiation between examination of men and women, with poverty emerging as an important factor influencing the uptake or not of policy. Wurririmi et al. (2013), and Nelson and Stathers (2009) in examples from Tanzania, show the important role women play in building adaptive capacity. The social capital that women bring to the villages in the Mwanga District meant that despite having limited access to livelihood assets, they were key drivers to creating the networks and labor required to conduct new and adaptive activities to respond to climate change.

Understanding gender sensitivities is revealed as being important to developing successful climate initiatives. For example, a case study from Bangladesh highlights that despite best intentions, the involvement of women in a solar energy committee and subsequent involvement in the project, in fact, created more work and difficulties for the women. Despite their committee membership no one listened to their voice and the extra energy provided by the solar project meant women in fact worked harder and longer hours due to increased availability of light (Wong 2009). This suggests that the underlying gender frameworks also need addressing before understanding how to develop gender effective climate responses. Nagel (2012) notes that where mores of masculinity dominate means that men's ideas of adaptation – which often favor large-scale engineering "fixes" – will take precedence and thus are less likely to be culturally palatable to women.

Conversely, initiatives in the Pacific (Lane and McNaught 2009) highlight the benefits of applying a gender-sensitive lens to climate change adaptation. Comprising efforts from the Red Cross and Red Crescent movement, the UNDP, and the WWF, this program identifies some best practices in gender-responsive programming. For example, the Samoan Red Cross has worked with locals to translate difficult climate change terms into nontechnical language accessible to women as well as men. Women have been invited to participate in early warning programs that harness their local knowledge. Another example is the development of a climate witness toolkit that is designed in response to the gendered needs or women in the region, thus enhancing engagement with and participation in climate adaptation initiatives.

In Uganda, Africa, adaptation for smallholder famers similarly faces challenges given the responses and decisions of male and female farmers differ. However, understanding how both genders make decisions makes it easier to apply adaptation programs that will work over the long term (Nabikolo et al. 2012).

In Australia, men and women also adapt differently to change due to their different positions in society (Altson 2011). In rural areas particularly women will be focusing on farm tasks, working off the farm, and trying to sustain social networks, whereas men will tend to be more involved in the on-ground activities of trying to farm under increasing climate impacts.

There is also a differentiated gender impact in indigenous communities. For example, in both Canada and Australia, men and women have different roles in environmental decision making and land and sea management. Men and women both use and have knowledge about the environment in different ways; hence their experience of how it will change and be impacted by it will be different. Aboriginal women in Tasmania, for example, are concerned about climate impacts on particular shells they use to make jewelry. Aboriginal men in Arnhem land and within the Arabana people of Kati Thanda-Lake Eyre are concerned about how increasing temperature and longer more extended drought will affect species that they hunt (Nursey-Bray et al. 2013). Women in Northern Territory are turning to aquaculture as an adaptation to building their livelihood options in the face of other threats to their society as a result of climate change (Petheram et al. 2013).

There are emerging examples of women acting proactively and asserting agency after disasters to protect themselves from further harm. One case is of Honduran women in La Masica, who initiated gender-sensitive training about early warning systems so that in the event of future disasters, they would know what to do. In Micronesia, women accessed traditional knowledge about hydrology to help them survive drought. In Bangladesh, where women sustained immense loss of life and other impacts in the floods of 2004, women in the district of Gaibana organized a committee that helped women know what to do in the event of future floods (CARE 2010).

Implications

This discourse analysis so far has found that two key discourses dominate the discussion around gender and climate change. One discourse explores the impacts of climate change on gender, while the other reveals the ways in which adaptation both drives and is affected by gender. Out of these dimensions a number of further characteristics emerge. First, gender in both discourses (although better differentiated in the latter) still primarily focuses on and uses the term *gender* to mean *women*. Most considerations of impact and adaptation (with the notable exception of Alston's work) focus on the situation of women in developing countries as against those in developed worlds. Finally, most work focuses on gender in the context of disaster – flood, fire, drought, and wind (hurricanes). This means that understanding of how gender may impact on and flow within the complicated networks of power and knowledge relations, relations that actually characterize day-to-day life, and most importantly the crucial minutiae of decision making within society is not as yet explored in depth.

Second, the two representations of impacts and adaptation tend to focus on the role of women as victims but as Terry (2009) argues, "Highlighting the agency that poor women, as well as men, demonstrate in the face of climate risk counteracts the tendency in the discourse to cast them as powerless victims. In fact, women often have an especially important role to play in adaptation, because of their gendered indigenous knowledge on matters such as agriculture."

There is a temptation in this area then for studies to fall into stereotypical representations of men and women, which makes policy making and decision making easier in one respect, but less effective as it does not address the nuanced nature of gender and responses to climate change. The discourse about gender thus has implications in practice. The question is, why? Clearly there are differences in power, incomes, access to resources, cultural mores, and biology that mediate gender effects in relation to climate change (Bjornberg and Hansson 2013). Climate governance frameworks, in both mitigation and adaptation, need to become more variegated to enable the fundamental reshaping of policy along the gender-sensitive lines that is needed. Is it possible to counteract this primary focus first on women and second on women as victims? How can governance be constructed such that women and men are both equally represented and given equal – if different – responsibility in decision making?

Ways Forward: A Gendered Governance Framework

Studies advance an adaptive governance response that will "contribute to preserving gender-differentiated distributions of power, solidify stereotypical gender roles and reinforce women's vulnerability to climate change" (Bjornberg and Hansson 2013, p. 717). Alternatively, Skinner (2011) suggests that societies must (i) change the way climate change and its responses are framed, (ii) create gender-aware policies and institutions, and (iii) create an enabling environment for gender-aware, people-centered climate change responses that contribute to social and gender transformation. Policy and governance could also proactively incorporate gender dimensions into preexisting planning processes.

Communities of Practice

However, in this chapter it is argued that the linguistic emphasis in research and programs on gender *as women* needs to change. Further research needs to be conducted into understanding how men, as well as women, are affected by and will respond to climate change; they also are both affected by climate change, albeit in different ways. Where clear inequalities exist between men and women, these need to be redressed in meaningful ways and ways that will address the power and other relations that really drive decision making. Given the importance of social networks in decision making, and the often dominant role women play in building, maintaining, reinforcing, and saving networks, the deliberative use of communities of practice as conduits for adaptive management is one way forward. As communities of practice (CoP) tend to emerge naturally rather than by intent and are situated within the social context within which they arise (Klein et al. 2005), they provide a practical forum within which to pursue a gender lens to climate change.

CoP was first defined by Lave and Wenger as "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (Lave and Wenger 1991). Wenger (1998) then extended the concept constructing CoP as the basic building block of social learning systems bound by three elements: joint enterprise, mutuality, and a shared repertoire of communal resources. Shared passions and problems (Wenger et al. 2002) and shared expertise (Ward and Peppard 2002) must be present for a CoP to naturally emerge. Barab et al. (2004) note that the ideal CoP is "a persistent sustained social network of individuals, who... [are] focussed on common practice and/or mutual enterprise." In practice, CoPs can be communities identified by the following traits: (i) the formation of group identity, (ii) the ability to encompass diverse views, (iii) the ability to see their own learning as a way to enhance learning, and (iv) a willingness to assume some responsibility for colleagues' growth (Grossman et al. 2001). Samuelowicz and Bain (2001) argue for the idea of communities of interest (CoI), which are characterized by (i) shared ideological and procedural assumptions and (ii) codes, slogans, and keywords accepted by that community. Finally, Klein et al. (2005) argue for a typology for CoP around the two key elements of structure and knowledge activity and include four models: (i) stratified sharing, (ii) stratified nurturing, (iii) egalitarian sharing, and (iv) egalitarian nurturing.

In the environmental realm, a CoP may manifest as a group working together on revegetation or climate adaptation programs. A CoP around blueberry production has enabled adaptive practice by those in the industry so they remain competitive (Hummel et al. 2012). Eishof (2003) argues the use of CoP can be enabling by creating the conditions for interdisciplinary responses to difficult problems. However, while some work has been undertaken on the utility of CoPs in the context of water management, community-based adaptation, or community engagement (Nursey-Bray 2012), its value as a form of governance is underutilized and as a mode of adaptive management has multiple advantages. In catalyzing around a common practice, the use of CoP as a collaborative governance tool enables the formation of roles for both men and women that will assist in achieving common goals (Baldwin and Austin 1995; Warhurst 2006). It will help ensure that practice moves from the individualized neoliberal norms to a more communal decision-making environment (Barr et al. 2012).

Second, communities of practice can galvanize social and adaptive learning as they provide the fora through which people can work together and learn from their mistakes but in a safe environment. Members of a CoP thus learn through doing, becoming, and belonging (Lawthorm 2011). Critical reflection is an important part of learning, and Ng and Tan (2009) highlight the efficacy of CoP in this context stating that they offer conditions for "critical reflective learning where reflection is implicit and intuitive in nature, and general and contextual in scope and object" – particularly appropriate for the issue of climate change. As the focus of the work is the common practice, it also creates a more democratic working environment, which allows for more gender-sensitive decisions to be made. In providing a buffer for people to work within, and the possibility of ongoing learning, adaptive capacity is built which in turn enhances the ability to deal with uncertainty. McDermott (cited in Bandy et al. 2008, p. 443) notes that "Communities of practice are ideal vehicles for leveraging tacit knowledge because they enable person- to-person interaction and engage a whole group in advancing their field of practice. As a result, they can spread the insight from the collaborative thinking process across the whole organization." While CoPs are perhaps hard to establish by intent, designing the conditions within communities to enhance learning is (Wubbels 2007, p. 232).

The use of CoP as an adaptive governance tool can also enable the incorporation of different forms and kinds of knowledge, and in many cultures where knowledge is mediated by gender, with men and women having different responsibilities for different sets of information, this again makes the governance process more equitable and helps all members within it to assert their own storylines and build diversity of views and perspectives. This is crucial to ensure best practice in knowledge management (Bishop et al. 2008). Importantly, CoPs play a role in ensuring governance processes of "becoming rather than being" which means that the temptation to fall into gender roles and constructions is harder. Dionnet et al. (2013) use an example of a simulated CoP in natural resource management (NRM) to show how CoPs can help communities become better at becoming involved in community management, a process of "becoming rather than being" as it is fluid over time. CoP can also create the conditions for innovation, vital in addressing a complex problem in complex systems like climate change (Barragn-Ocana et al. 2012). This also enhances inclusivity (Angelides et al. 2008).

The fluid nature of CoP also means that they have the capacity to change and adapt as the problem changes or with the introduction or exiting of new and old members. Given the focus is on practice, CoP creates a spatial rather than geographical governance arrangement which allows flexibility in the decision making or, as Gammelgaard (2010) shows, virtual communities of practice. Robinson and Raymond (2013) in an Australian case study of communities of practice of rural landholders found that working with CoPs enabled them to better understand the factors affecting decision making about climate adaptation. As such, CoPs could similarly assist in getting deeper understanding of factors motivating gender in adaptation and thus how to construct decision-making processes within formal institutions. For example, the Women's Environment Network, in Australia, is a CoP that actively promotes and educates women about climate change with a view to building their capacity, across multiple sectors, and enabling them to invest in formal policy making about it via mechanisms such as media, events, or committee work. In a review of global CoPs reflect that they offer flexibility as well as stability as a means of governance. Finally, a CoP will support and legitimize governance at local scales, which will assist women in particular to assert their rights and capacities to be part of local adaptation practice. This will help in building sustainable communities that are in transition (Barr and Devine-Wright 2012).

The overarching advantage of seeking to utilize CoP as conduits for gender appropriate governance in a climate change context is the fact most people are already members of existing networks and CoPs. For example, "GenderCC" is a list serve of over 450 members which "is dedicated to information exchange and networking among those committed to gender justice in climate change, on topics relating to gender and climate change issues, women's rights, gender relations and gender justice in the context of climate change and climate related policy making" (http://www.gendercc.net/about-gendercc/network.html). Not only does this network galvanize around a community of practice focused on gender and social justice but also links multiple network together – GenderCC also hosts or provides links to many other networks working in related areas and at an international scale. Thus, there is no need to “reinvent the wheel” but build on existing frameworks, to streamline their focus, and help reshape power and knowledge relations so they become gender sensitive.

Conclusion

In this chapter, a discourse analysis has provided insight into how gender is treated in the context of climate change. The chapter documented two key discourse storylines, the first being the argument that women will be disproportionately affected by climate change and the second that women although having resilience and some agency will also be disadvantaged in the context of adaptation policy. Analysis of these studies further highlights an emphasis on women over men and a focus on developing over the developed world. While it is clear that the position and role of women in climate change contexts need strengthening, it is important to also find ways of building governance frameworks that incorporate women *and* men, thus providing an appropriate gender lens to decision making. Applying an adaptive governance approach that deliberatively utilizes existing communities of practice is suggested as one way forward. Communities of practice both build on existing networks while providing future opportunities to do things differently and make better decisions. Ultimately, gender matters, thus a system of gender-sensitive governance, one which recognizes the collective responsibility and needs of both women and men, will be the most adaptive and resilient over time.

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Improving Capacities and Communication on Climate Threats for Water Resources Adaptation in Paraguay

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Abstract

Successfully improving the capacities and communication on climate adaptation in water resources in Paraguay requires enhanced acceptance and understanding of both climate change and variability adaptation (CCA and CVA respectively). This is firstly to realize that the country has some intrinsic vulnerability being already impacted by climate threats on specific geographic and time scales. Climatic trends, cycles, and extremes impact the rich agropastoral basis of the economy, e.g., GDP and exports. The current deficit of CVA implies some lack of CCA to future scenarios. Secondly, we suggest focusing on building capacity on climate science and management through the (i) reinforcement of science-driven knowledge, e.g., future climate projections and scenarios; (ii) enhancing the communication of climate services within the Rio de la Plata basin (RPB) to make them more user-friendly; and (iii) training of climate science managers (CSM) capable of understanding and communicating climate-related issues, as well as to plan management policies. Thirdly, the coproduction of knowledge by natural and social scientists, engineers, managers, and users is necessary in order for them to be better informed and to produce flexible scenarios and plans. Journalists should participate to be acquainted with climatic events and time scales. Some of these activities have already been done or are being developed: (i) the reinforcement of science-driven knowledge, i.e., a dynamic climate downscaling was carried out with PRECIS tool; (ii) a master's degree in global change was created; (iii) regional climate services are improving; and (iv) the understanding of the impacts of CCA and CVA is increasing. A climate forum can provide the required platform to build capacity and communication awareness and the coproduction of knowledge with elected authorities, stakeholders, and journalists, further allowing for a consensual climate adaptation process.

Keywords

Paraguay River basin • Rainfall regime • Climate variability impact • Building capacity • Climate management • Mass media

Introduction

Paraguay is vulnerable to the impacts of climate change and variability; however, the country's social, economic, and environmental sectors do not perceive it yet. The main conclusions of the United Nations Economic Commission for Latin America and the Caribbean (ECLAC/CEPAL) named "Regional Study of Economics of

Climate Change South America" (CEPAL 2010) on climate vulnerability, impacts, and adaption on water resources and agriculture in Paraguay can be summarized as follows:

- The country is rich in water resources and does not have to implement adaptation measures yet but for specific cases. However, it could be impacted whether locally or seasonally by 2050.
- Summer crops and livestock (beef and dairy cattle) will suffer the effects of warming and rainfall regime changes, whether by less precipitation during summer or more intense short-term rainfalls; thus water storage could become a usual practice by 2050.
- The impact of droughts in terms of affected people should increase from the baseline (2007) by 23 %, 39 %, and 74 % by 2020, 2030, and 2050, respectively.

Since 2009, the pressure of climate stressors is very likely increasing. Gross domestic product (GDP) average country's increase from 2009 to 2013 was above 5 % (from −4 % to +14 %, BBVA 2013; DGEEC 2013). More than half of these changes are associated with agriculture and livestock production and exports (soybean and beef). The GDP will continue increasing at high rates during 2014 (BBVA 2013) which will push both the inflation and the interest rates (García 2014).

The observed warming and wetting signals over South America (Skanski et al. 2013), the likely expected warming and uncertain precipitation evolution for 2020–2050 (Bidegain et al. 2012; Pasten and Giménez 2012), and the disaggregation of climate impacts on regional and seasonal basis in Paraguay suggest that adaptation to climate change could not be evaded over the next decade.

This article focuses on building capacity and communication on climate threats on water resources adaptation in the Paraguay River basin as follows: (i) regional climatic and water resources information; (ii) the frameworks of climate variability and change adaptation (CVA and CCA); (iii) the perception of climate variability in the media; (iv) the existent regional climate scenarios and services useful to support both current climate variability and future climate change adaptations; (v) the development of a master in global change degree devoted to climate science and management within the Paraguay River basin (PRB); (vi) the regional climate services to cope with climate variability within La Plata basin (LPB); and (vii) the communication of climatic data to stakeholders.

Geographical Setting and Climate Vulnerability of Paraguay

Paraguay is located in the center of South America, having 406,752 km^2 land area with a population of 6.7 million inhabitants (DGEEC 2013). It accounts for 13 % of the Rio de la Plata River basin (3.1×10^6 km^2, La Plata basin from now), almost one third of which within the Paraguay River basin (the Paraguay basin from now on). The country is divided by the Paraguay River into two major regions – Western (Chaco) and Eastern (Fig. 1) – and 17 departments (provinces). The former is part

Fig. 1 The Rio de la Plata basin and Paraguay. The Paraguay River divides the country into a western dry region named El Chaco and an Eastern wet region (es.wikipedia.org/wiki/Cuenca_del_Plata)

of the ecosystem known as "Gran Chaco Americano" shared with Argentina and Bolivia, a large plain in which the main economic activity is beef production. The latter is confined between the Paraguay and Parana rivers, having a more undulating topography, good drainage, and large subtropical forests. Because of the increasing exploitation of agriculture, e.g., soybean and livestock, the Eastern Region, border with Argentina and Brazil, suffered a high rate of deforestation over the last few decades. The Pantanal wetlands shared by Paraguay, Bolivia, and Brazil are placed to the north of the basin.

The agropastoral activities use about 70 % of the available water resources. Threats in their ecological and hydrological functions from climate change and variability are already installed in the region, requiring a proper planning and management of water resources to successfully cope with current variability and to adapt to future changes. Thus, water availability and allocation is central for the prosperity of Paraguay and the other countries of the La Plata basin (Argentina, Brazil, Bolivia, and Uruguay) which are world's leading exporters of soybean and beef, as well as strong producers of other cereals and dairy products.

Riverine populations are the most vulnerable to climate risks due to floods and inundations. The consequences of long-term climate change and variability in the Paraguay basin are not well known yet, but observed changes in extreme events have been associated with loss of life, economy, infrastructure, and biodiversity of ecosystems (Wantzen et al. 2008).

Future climate scenarios (2030–2080) for Southeastern South America (SESA) centered on Paraguay were generated for temperature and precipitation (Alves and Marengo 2010; Bidegain et al. 2011, 2012; Pasten and Giménez 2012) from global climate models (GCMs) outputs with IPCC socioeconomic scenarios SRES A2 and

B2 (Carter et al. 1994). Despite the uncertainties inherent in this type of construction of future scenarios, the greatest warming is expected over the north and northwest (Chaco and the Paraguay basin) and the least over the southeast (Eastern Argentina, Uruguay, and Southern Brazil). Paraguay would experience for the 2020s and 2050s a warming around +1 °C and 2.5 °C, respectively. There is a significant difference in the precipitation estimation; the greatest reductions (−6 %) would be located over the Paraguay basin and the largest increases (+5 %) in the Eastern Region. Most models' outputs show an increase in rainfall over November and December. This trend should already occur in the 2020s but should be more noticeable in the 2050s, when it is expected up to 1 mm/day in October at Asuncion and other sites within the PRB.

Climatic and Hydrologic Setting

Paraguay has a great regional climatic variability. The vegetation in the Chaco Region is semiarid to the northwest and subhumid megathermal savanna to the northeast and the Paraguay River basin. The rest of the Eastern Region is humid wet megathermal with maximum humidity levels in the departments of Alto Paraná, Itapúa, and Canindeyú (Table 1 and Figs. 2 and 3). Rainfall has an annual cycle with a period of high (October to March) and one with low rainfall (April to September). The Western Region has minimum precipitations during the months of austral winter (July and August), when rainfall becomes scarce, and the maximum is observed during summer (December and January). Although in the Eastern Region, especially in the southeastern zone, the same seasonal variation is also observed, it is not as pronounced as in the Western Region.

The behavior of the annual rainfall totals (Table 1) for the period 1961–1990 shows a minimum of 596 mm/year in Boquerón (Chaco region) and a highest of 1,667 mm/year in Itapúa (Eastern Region) where two large hydroelectric power generation dams are located (Itaipú and Yacyretá). The seasonal rainfall is well defined, the summer (DJF) and spring (ND) being the rainiest and the winter (JA) the driest.

Table 1 Yearly means of temperature and accumulated rainfall (1961–1990) for 7 of the 17 departments of Paraguay (Source: Climatic Research Unit-CRU, Hadley Centre, UK; 50 × 50 km)

		Yearly mean temperature and accumulated rainfall	
Department	Region	°C	mm/year
Alto Paraguay	Chaco	**25.2**	839
Alto Paraná	Eastern	**21.3**	1,620
Boquerón	Chaco	24.1	**596**
Canindeyú	Eastern	22.0	1,543
Central	Eastern	22.7	1,401
Itapúa	Itapúa	21.4	**1,668**
Presidente Hayes	Chaco	23.7	1,013

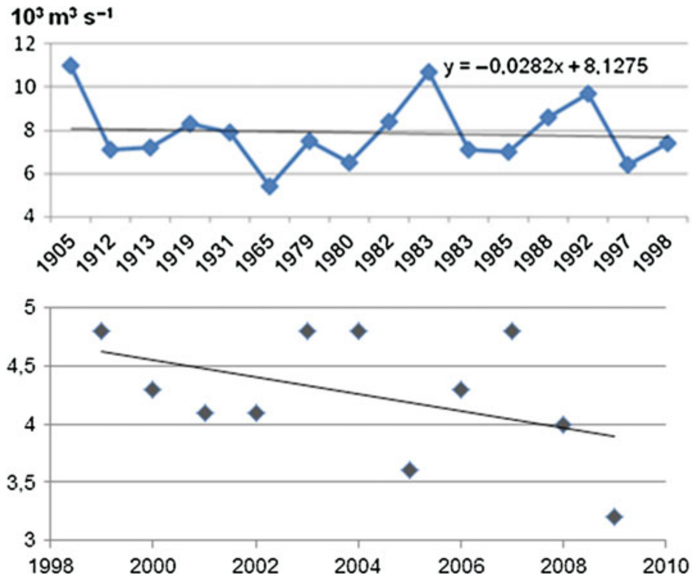

Fig. 2 Paraguay River floods at Asuncion from 1905 to 1998 (*above*, Barros et al. 2006) and from 1999 to 2009 (*below*)

Water Resources and the Paraguay River Basin

The nature and extent of current environmental impacts within the Paraguay River basin are of mixed nature: primary human induced, such as deforestation and land degradation, and increasingly climate induced, mostly climate variability impacts such as drought and flooding.

Some of the environmental impacts on the La Plata basin and particularly the Paraguay basin water resources are the following (modified from Tucci and Clarke 1998):

- Evolution of hydroelectric dam reservoirs in the upper Parana basin in Brazil since 1960
- Deforestation since 1950
- Agricultural intensification since 1970
- Urban developments due to changes of inundation, navigation, and conservation patterns in the upper Paraguay River basin
- River flow increase since 1970 attributable to changes in land cover and climate

The Paraná and Uruguay rivers together with Paraguay River (a tributary of the former) are the main tributaries of the La Plata River. The Paraguay River has a low gradient in its origins giving rise to vast Pantanal wetlands (Fig. 1),

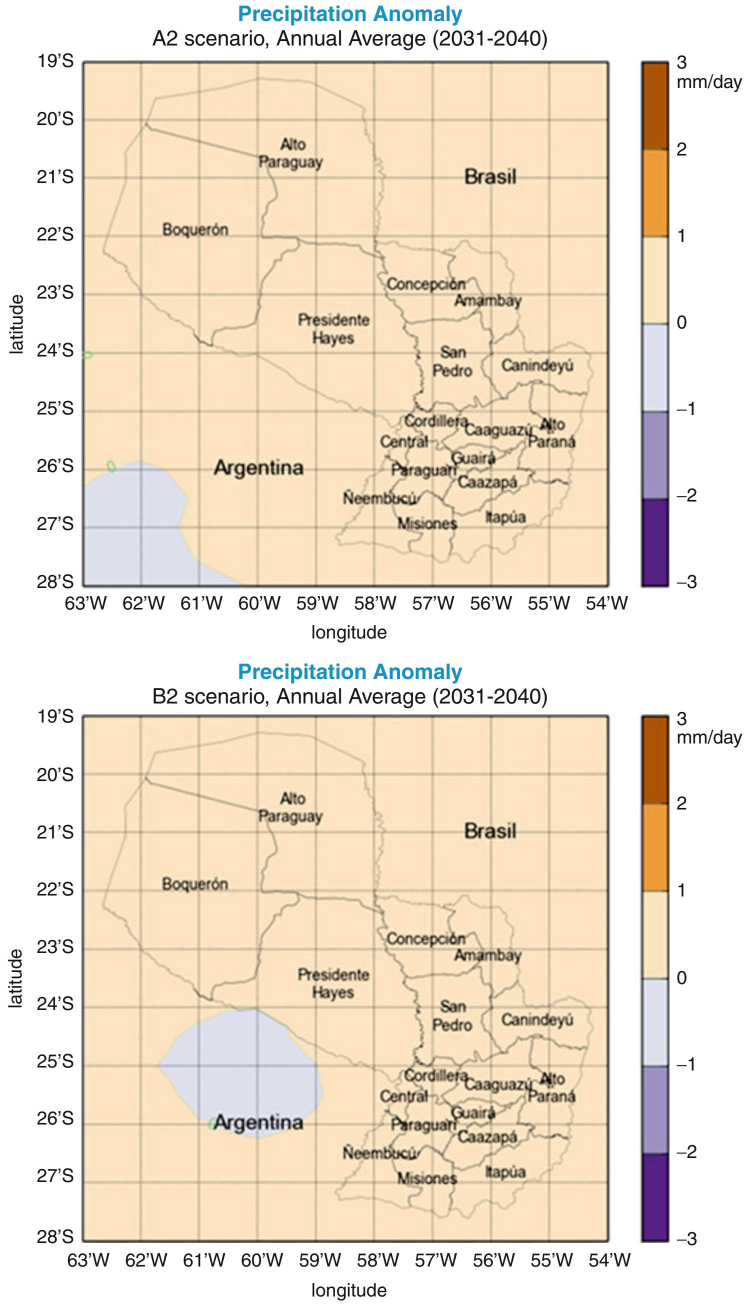

Fig. 3 Expected precipitation (mm/day) anomaly for 2031–2040 from the climatic reference 1961–1990: (*above*) scenario A2. (*below*) scenario B2 (From Pasten and Giménez 2012)

the largest wetlands in the world, with ca. 220,000 km^2. This gradient causes a delay in the flood wave around 4 months between the north and south of the Pantanal region.

The Paraguay River flow is maximum during austral winter and minimum in September and January. Average river flow is 3,000–4,000 m^3/s (varying from 800 to 12,000 m^3/s). These extremes are about 1–9 m water level at Asunción. Most floods in Asuncion take place between May and July in phase with the winter maximum annual flow cycle. They are originated in the upper and middle Paraguay basins, mostly related to El Niño Southern Oscillation (ENSO) warm phase (El Niño) and are independent of the Pantanal output (Barros et al. 2004). The typical occurrence of floods up to 2–3 m is each 3 years covering 80 % or plus of the country's plains reaching 4–5 m or plus during El Niño events, e.g., 1983. Wetlands have a great flood buffer capacity protecting agriculture, infrastructure, and human settlements (Neiff et al. 2000).

Time series of yearly maximum floods during the period 1905–1998 shows a slight decreasing trend with cycles, such as the one from 1999 to 2009 (Fig. 2). To forecast these cycles of ca. 10–15 years is a challenge to manage the basin.

The potential impacts of climate change in the Paraguay basin are the increases in temperature, rainfall intensity, and the frequency and severity of extreme events such as inundations, heat waves, storminess, and prolonged droughts. These events would impact agriculture, livestock, and human populations due to the increased risk of urban flooding and water-borne diseases. The rise in upper basin erosivity as a consequence of summer rainfalls and of the sedimentation in the lower basin should increase the risk of droughts and forest fires because of greater evapotranspiration and less precipitation during the low-water level period. These changes should impact the aquatic ecosystems all over the basin (IPCC 2007; Project Sinergia 2011). The data presented in Table 1 which shows likely temperature increase and uncertain rainfall evolution support changes in evapotranspiration.

Climate Change and Variability Adaptation

> Adaptation is "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities". (IPCC 2007)

Because of the extensive uncertainties that exist in the future drivers of and responses to climate change, future scenarios are necessary to explore the potential consequences of different management response options (Moss et al. 2010). The construction of climate scenarios and adaptation strategies (Climate Science Management, CSM) evolved over the last two decades from a science-driven approach led by earth and natural scientists to a citizen-driven one where social scientists have an important role.

However, the concepts and framing of adaptation are not the same worldwide. Here "climate adaptation" is referred to as "The adjustment to any threat or harm from continuous climate change or discrete climatic and meteorological events"

(Nagy et al. submitted). Since the strong El Niño event of 1997–1998, ENSO-related variability has become the Climate Science Management priority in Latin America (IPCC 2001) including Paraguay (Grassi 2001; CEPAL 2010). We take for granted that climate adaptation is a top priority in our region and suggest that the highly distributed extreme hydrometeorological events since 2012 are changing the perception and interpretation of climate threats and vulnerabilities worldwide, as well as the need for both mitigation and adaptation now.

Three framing of adaptation can be distinguished (Dupuis and Knoepfel 2013):

- Climate change adaptation (CCA)
- Climate variability adaptation (CVA)
- Vulnerability-centered adaptation (VCA)

These authors argue that a lack of adaptive capacity is not sufficient for explaining the implementation deficit related to CCA which relies on different limiting factors depending on the context. A lack of adaptation to current climate variability and observed change is a failure to keep pace with development in the "adaptation deficit" (Burton 2004). This concept captures the notion that countries are underprepared for current climate conditions, much less for future climate change. The shortfall is not the result of low levels of development but of less than optimal allocations of limited resources (EACC 2012). "Persistent vulnerability to climate variability is a symptom of an adaptation deficit in socio-ecological systems" (Preston et al. 2013).

Climate Change and Variability in the Media

The media ABC Color is an important disseminator of information in Paraguay based in Asunción. It is the most widely circulated daily newspaper, fostering civic consciousness of citizenship providing sustained support for education at all levels. It summarizes important concepts, which may reflect and even create public opinion on climate change.

When we were finishing this article, a press article about the current climate extremes was published in Paraguay (ABC Color Newspaper, January 16, 2014). We do not agree with all what is written in the article, but have synthesized the most important concepts because it could reflect and/or create public opinion about climate change. As many press articles do all over the world, it mixes climate anomalies, variability, and change and accuses the government of inaction.

> Paraguay is gradually suffering the impacts of climate change. There are extremely hot days and heavy rainfalls, without precedent in the last few decades. Experts from the unit of Risk Management of the Ministry of Agriculture and Livestock highlight the impacts of water stress on crops, fruits, pasture and livestock. The drought and heat excess difficult navigation in the Paraguay River. There is little action on mitigation or adaptation. The Directorate of the Environment (SEAM) generates the ideas for mitigation and adaptation. Notwithstanding, these problems are not having an adequate response yet.

We agree with ABC with regard to the impacts and the need of increasing actions, especially preparedness to climate extremes and adaptation. The increase in climate analysis and modeling, information and public awareness, and education of managers are key steps to facilitate government and NGO's climate adaptation planning.

How to Deal with Adaptation Under Uncertainty in Paraguay?

Here we suggest that in order to cope with variability, emphasis must be put on building capacity to develop a community of experts in Climate Science Management and the coproduction of knowledge with the aim of increasing public awareness and trust, through a participatory and informed process. Climate variability adaptation (CVA) facilitates coping with unexpected extremes and planning climate change adaptation (CCA).

The countries of the La Plata basin have been learning to cope with variability (CVA) to sustain growing local consumption and food exportation. However, "managing variability" seems not to be enough because of the ongoing changes in climatic patterns and the high level of dependence their economies have on climate, water resources, and grasslands.

Under a likely warming scenario of 1 °C or plus and uncertain rainfall in a decade or so, the top priority CVA in the Paraguay basin should evolve together with planned CCA plans based on natural or socioeconomic accepted thresholds to continue a sustainable development. Even if Paraguay is very rich in natural resources and the Chaco region is naturally dry and resilient, it is vulnerable to changes in water availability which could worsen under expected changes (CEPAL 2010). A good strategy could be based on the concept of Butler and Coughlan (2011) "Adapting to variability before change and using preexisting adaptation strategies for climate variability as a proxy for future adaptation planning" Climate variability has been a driver to increase regional capacities to forecast and manage resources and production under uncertainty which is basically risk management (Jones 2010), even if risk probability is often only estimated. There is also a need of better vulnerability assessments and VCA.

The region is suffering an increase in seasonal, interannual, and decadal variability. Thus, to forecast short-term events within the boundaries of synoptic and climatic scales is becoming more difficult in spite of more resources allocated.

There are several ongoing climate vulnerability, impacts, and/or adaptation projects on water resources, agriculture, health, and biodiversity in Paraguay, mostly with neighboring countries Argentina, Brazil, and Bolivia (CEPAL 2010; Project Sinergia 2011, www.portalsinergia.org.br; Báez et al. 2014; REGATTA Project "Gran Chaco y Cono Sur," www.granchaco13.wix.com/comunidad). They are mostly focused on CVA, environmental degradation and preservation, early warning and monitoring, risk analysis, and transboundary water.

From now on, we present some activities we have been developing over the last few years to build capacity to understand global change science and management.

Future Climatic Scenarios

A dynamic climate downscaling centered in Paraguay was carried out with PRECIS tool (UK Met Office Hadley Centre-HADC) based on the runs of the HadRM3P mesoscale Global Circulation Models (Pasten and Giménez 2012).

The comparison between the observed climatology (data from Climatic Research Unit-CRU, University of East Anglia, UK) and the modeled one for the period 1961–1990 shows the model reproduces very well the precipitation in much of Paraguay, except in Alto Paraguay, Boquerón, and Presidente Hayes in the Chaco region. The correlation of expected temperature trends for the time frame 2011–2050 is significant (95 % confidence interval) for temperature in the departments of Alto Parana, Boquerón, Central (Asuncion), Itapúa, and Presidente Hayes with both scenarios A2 and B2, whereas the expected increases in precipitation are not significant. The temporal behavior of rainfall is quite well reproduced but overestimated in the months of high precipitation. In the north, center, and south of the Eastern Region, both climatologies are quite similar. With regard to temperature, the model reproduces very well the seasonal behavior in the Chaco region. However, in most cases, the model underestimates the average temperature in the hottest months, whereas in the Eastern (wet) region, there is a good fit between both climatologies. Modeled future increase in both precipitation and temperature for 2013–2040 is shown as anomalies (Figs. 3 and 4, respectively).

The future A2 and B2 scenarios for 2031–2040 can be summarized as follows: a marked and significant increase of the mean annual temperature, with increases between 1.3 °C and 1.6 °C for the scenario A2 and 1.1–1.4 °C to the B2 scenario from the period 1961–1990. The precipitation shows a slight increase for 2040, but the trend is not significant.

The outputs of the Japanese MRI-CGCM2.3 high-resolution model for SESA (Bidegain et al. 2011) give quite similar results. Yearly mean temperature and precipitation fields for the La Plata basin are very well and well represented, respectively, for the calibration period (1979–2003) which already includes a significance increase in both parameters. Expected warming varies from +1 °C to +2 °C for 2015–2039 and from +3 °C to +4 °C for 2075–2099, which are less to the southeast and greater to the northwest of the La Plata basin. Thus, for the time horizon 2040–2060, a likely range is +1.5–2.5 ºC, which is in close agreement with the previous results from GCM downscaling. Precipitations are expected to increase in Eastern Paraguay, Southern Brazil, and Uruguay by + 5 % (2013–2039) and 10 % (2075–2099) with regard to 1979–2003, which is very similar to the values around 1990.

Regional Climate Services: Technological Resources to Cope with Climate Variability Adaptation

One of the drivers of climate variability in the La Plata basin is El Niño Southern Oscillation (Barros et al. 2004, 2006). However, there are deficits in the knowledge of other climate drivers, and so climate prediction is still limited.

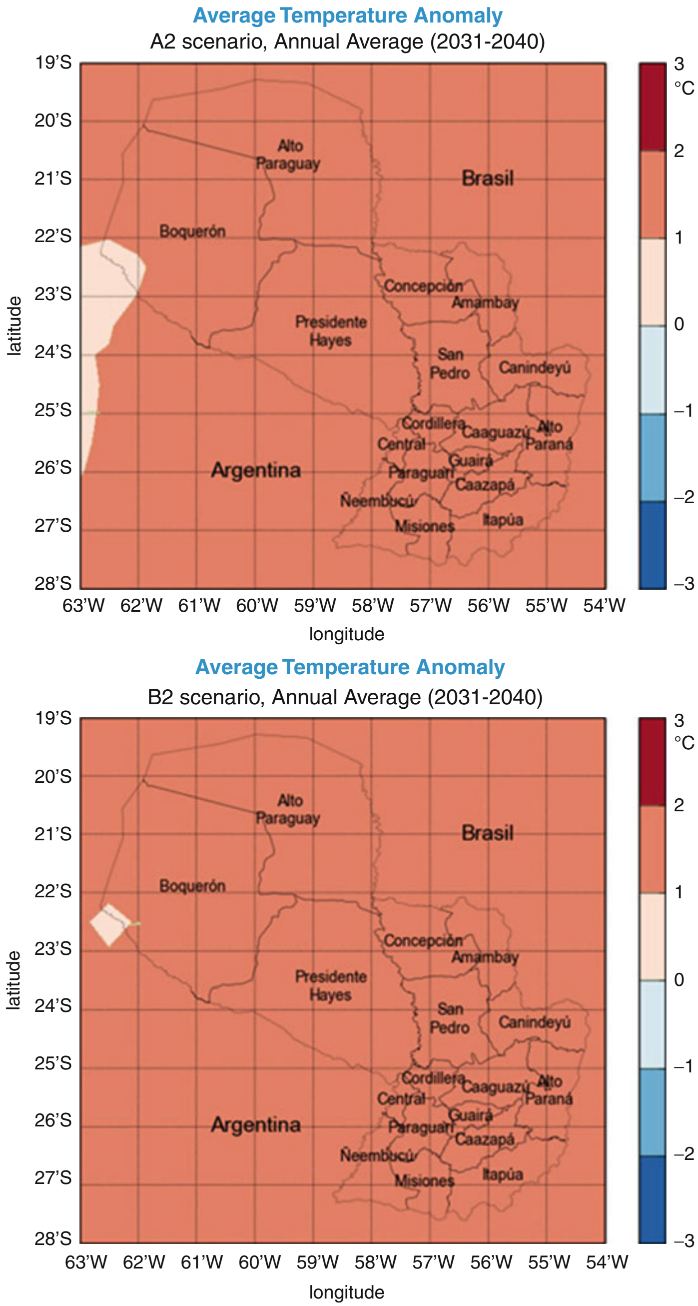

Fig. 4 Expected yearly temperature anomaly for 2031–2040 from the climatic reference 1961–1990: (*above*) scenario A2. (*below*) scenario B2 (From Pasten and Giménez 2012)

Since December 1997, there have been developed regional climate forum for Southeastern South America (SESA) in the form of a climate forecast consensus expressed as tertile probability (less than the normal, normal, and above normal) for the region between the latitudes 19 °S and 35 °S and to the east of the Andes. This prognosis is developed by experts of the Meteorological Services of Argentina, Brazil, Uruguay, and Paraguay; the Center of Weather and Climate Forecasting of Brazil; the University of Buenos Aires with its partners; and the University of the Republic of Uruguay.

While these forecasts are widely used by the various user sectors, an urgent upgrade of both the methodology of development and communication to users is required.

The World Meteorological Organization (WMO) joined the Board of Intergovernmental Climate Services (JISC) within the Global Framework of Climate Services in July 2013. This initiative seeks to develop climate services at global, regional, and local scales as a response to climate variability and change. Four priority areas were defined:

- Food production and agriculture
- Water and energy
- Health
- Risk reduction of natural disasters

The climate services are based on the following pillars:

- Scientific knowledge
- Climate observing networks
- Platform for users
- Training

The overall goal is the production of climate forecasts on monthly, seasonal, yearly, and decadal time scales, oriented to the four sectors of users aforementioned. Two Regional Climate Centers (RCCs) are being implemented in South America:

1. The western center placed in the International Center for Research on the El Niño Phenomenon (CIIFEN), with headquarters in Guayaquil, Ecuador (http://ac.ciifen-int.org/rcc/)
2. The southern center (RCC-SAS), whose concept is a virtual center, managed by the meteorological services of Argentina and Brazil, with the participation of the meteorological services of Paraguay and Uruguay

These centers are staffed with a structure and governance and must comply with the standards of the WMO. The RCC-SAS developed an experimental website, which will be available in the short term. Both centers will monitor the main climatic variables as well as weather forecasts, supported by the regional climate forum.

Capacity Building: The Master Degree in Global Change and Climate Risks

The capacity of communities to adapt to global change and climate threats is determined by their level of development and allocation of resources and its scientific and technical capacity. The direction of climate change is uncertain, so that emphasis should be put in the increase of the capacity for adaptation and risk management in relation to key sectors in the Paraguay basin, such as agriculture, water resources, biodiversity, and health. To decrease the impact of climate threats, adaptation must be integrated into the overall development policies (Watson et al. 1998), and scholars must promote an interdisciplinary knowledge management to face global change and its impacts. It is important to address the threats from climate change and variability issues beyond science, without forgetting that the human dimensions are indispensable so that climate adaptation be effective.

Global change is recognized as the greatest challenge that humanity has to face in the coming decades, being a challenge for science, given that it transcends the traditional boundaries between disciplines. This requires an integration of inputs that overflows the conventional structure of the existing educational programs. There are two important questions that require more qualified staff in global change teaching and research with regard to water resources. Firstly, how does it work for the Paraguay basin, within the regional system, in relation to the biogeochemical cycles? Secondly, how could the land use and climate changes affect the functioning of the Pantanal-Paraguay ecosystems?

The Polytechnic Faculty of the Universidad Nacional de Asuncion (FP-UNA) developed a master's degree (MSc) in global change with emphasis on climate risks (Coronel et al. 2012) offered since 2014. This degree was designed to understand, from the scientific knowledge, factors and sectors in which there is a need to intervene (management). The program will trigger among its participants a search process for innovative alternatives that have to be translated into the design and implementation of research and development projects and implementation of alternative technologies in the productive processes, e.g., agriculture and hydroelectric power generation. It is hoped also to reinforce the generation of novel regulations, education, awareness, and citizen participation. Graduates will be knowledgeable about the use of climate scenarios and the approaches to evaluate climate vulnerability, adaptation, mitigation, and risk management.

The degree emphasizes education and research on global change science and management. To achieve this goal, professors and experts from Paraguay and the region have been integrated within the program. The MSc degree is addressed to graduates in sciences, social sciences, agriculture, and health that are working or have the chance to work as teachers or researchers or are at the forefront of public and private units which are engaged in environmental issues sensitive to climate change and variability.

Communicating Climate Data and Scenarios to Stakeholders in Order to Improve Adaptation

What do stakeholders and decision-makers need to know in order to plan and implement adaptation? When the media analyze climate issues, e.g., the ABC Color Newspaper article of January 16, 2014, focus is on to the current climate, especially extremes. Thus, they may both increase public awareness and confusion about climate threats and perspectives, searching more for government level responsibilities than focusing on climate change and variability. We suggest building capacity and public awareness on climate science and management.

The director of the Risk Management Unit of the MAG had said (ABC Color June 6, 2011) that he is taking into account the regional climate services forecast and that he is aware of the increasing trends in temperature and precipitations. He outlined the need to have a good prognosis and communication to farmers on extreme meteorological events to manage crops and of El Niño events which can cause floods in the upper and middle RPB where agriculture and livestock activities are predominant.

In order to achieve a better communication between scientists and stakeholders, there needs to be a coproduction of knowledge (Roux et al. 2006; Biesbroek et al. 2009; Nagy et al. 2014). We suggest to focus on the enhancement of both top-down and bottom-up approaches which requires not only resources but also the integration of all involved representative citizens (stakeholders at all levels of making decisions). However, we must avoid the illusion of public participation being that crucial as to scientists' information and feedbacks being underestimated. The ways to achieve a better integration of experts from the academia, government, and users are by means of education and training, e.g., the MSc in global change, and the increase of public awareness and participation through workshops and webinars. Stakeholders are included to not only be informed and give their opinions but also participate together with experts on building future scenarios and participatory planning. These meetings should serve to discuss current priorities with expected future threats, harms, and thresholds. The participation of journalists is desired in order for them to be acquainted with climate issues and to communicate them.

A simplified mix of risk management and adaptive management approaches to deal with both climate threats and uncertainty could be summarized as follows:

- What are the main directions of change?
- To focus on "what if" and "what is at risk" statements.
- To integrate scientists and stakeholders the best available "science and monitoring in order to gradually change plans accordingly to how climate changes/varies."
- To better communicate current and expected climate evolution and associated impacts at all climate management time scales.

A good example of participation and communication on what has been done over the last 2 years is the periodic webinars of REGATTA Climate Adaptation Project Gran Chaco y Cono Sur Americano (http://kp.iadb.org/Adaptacion/es/Cono-Sur/Paginas/inicio.aspx).

Conclusion

In order to achieve a better communication of climate information and capacities to address adaptation regarding water resources will require the following steps:

- To assume the threats of current and plausible climate futures
- To increase scientific knowledge and monitoring
- To train climate science managers in order to transcend the boundaries of disciplines and climate threats and impacts
- To increase the quality of climate information from both the climate services and the media, further allowing to have a better informed population
- To produce cooperative knowledge based on both the science and the needs and perceptions of stakeholders

We, as scientists and engineers from the academia and government, strongly believe on scientific knowledge and – as practitioners – the need of integrating local knowledge. We support the promotion of climate forum on water resources, agriculture, hydroelectric power generation, and riverine populations' risks, where the state of the art on climate variability and change and the perception and needs of stakeholders are discussed. We also believe that it is necessary to avoid the illusion of participation as it was the "approach to truth" but the way to generate feedbacks to learning by doing.

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International Policy on Climate Change and Its Influence on Russian and Belarusian Legislations and Practice

Siarhei Zenchanka

Contents

Abstract

This chapter attempts to illustrate the influence of international policy and legislation on national ones and their implementation in practice of environmental protection. Comparative analysis norms of Russian and Belarusian legislation in climate change with international policy are used. The practical results of realization of these norms are considered. The comparison of environmental legislations of Russia and Belarus with international ones shows the concurrence and the difference of the laws. Consequently, there is the need to develop new laws and improve the existing ones. This chapter considers possible ways to improve the national legislations in climate change and presents a good practice in Russia and Belarus in environmental protection which shows social responsibility of leading enterprises. Climate change impact on economic development is considered. Russia and Belarus are the countries where the quantity of greenhouse gases is below the limit. Nevertheless, a great work has been done in these

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countries to limit emissions. The national policies are not always concurrent with international, which tend to remove these countries from the world process of sustainable development.

Keywords
Environmental policy • Climate change • International legislation • National legislation • Greenhouse gases • Environmental protection

Introduction

The climate changes have always been present in the Earth history. Glacial periods alternated with the periods of warming, i.e., ages of reduction of glaciations (interglacial periods). Now the Earth is in the Quaternary period which ends the Cainozoe. Approximately 12 thousand years ago, the Holocene began which is being continued to present time and is characterized by relatively stable climate. The last climatic period of the Holocene is the Sub-Atlantic period. The average annual temperature in the Sub-Atlantic period was lower than that in the previous Atlantic period (World Climate 1934). During the Sub-Atlantic period, there were fluctuations in temperature that led to ecological effects influencing life and activity of people.

This period can be divided into several ages (Chromov and Petrossiants 2012):

- Period of warming (2500–1600 years ago) when climate conditions moved to modern conditions; Period of dry and warm climate (1600–1200 years ago, fourth–eighth centuries A.D.)
- Period of soft and warm climate, small climatic optimum, (1200–800 years ago, eighth–fourteenth centuries A.D.)
- Fall in temperature, small glacial period (800–150 years ago, fourteenth–nineteenth centuries A.D.)
- Climate warming from the middle/end of the nineteenth century to present time (with a small fall in temperature in the middle of the twentieth century and renewing of warming in the last half century)

These climate changes were due to natural phenomena in general – the sun activity, tectonic process, and change in the parameters of the Earth orbit. The changeability of the climate system is determined by different mechanisms of positive and negative feedback between the components of the system: atmosphere, ocean, cryosphere, land surface, and biosphere, which can have an impact at time period from 10 to 100 years.

The process of the warming acceleration started from the second half of the twentieth century which is linked with anthropogenic activity. It was established that the influence of anthropogenic activity is due to the action of the several main factors:

- The increasing quantity of atmospheric carbon dioxide and some other gases come to atmosphere due economic activity so-called hotbed gases or greenhouse gases (GHG)
- The increasing volume of atmospheric aerosol intensifying the dispersion and absorption of radiation in aerosol particles
- The increase of heat quantity formed due to economic activity that acts on atmosphere heating

The first factor of anthropogenic climate change has the largest influence. Therefore, at the present stage, it is very important to combine the efforts of mankind to reduce the influence on the Earth climate of the economic activity connected with the increase in quantity of GHG in the Earth atmosphere.

It is necessary to consider the third factor, i.e., the growth of the quantity of heat due to economic activity as the Earth is an open system and the input flow of energy must be equal to output flow of energy for its stable operation. When this condition is not fulfilled, the Earth will be heated or cooled. Using of mineral sources of energy of the Earth leads to the increase of the Earth temperature.

The work of heat power stations causes the increase of the mass of atmospheric aerosol which results in strengthening of scattering and absorption of radiation on its particles (the second factor of anthropogenic impact on climate).

The aim of this chapter is to analyze international and national policies of Russia and Belarus in the area of climate change and to consider the implementation of these policies.

Methodology

International legislation has priority over the national one. At the same time many international agreements do not have the status of law, and to put them into effect, the consent of a certain number of parties is required. Documents adopted at national level do not sometimes meet international agreements. The comparative analysis of international agreements and national documents will help in understanding of the national aspects of legislation.

Materials from the official sites of UN, EU, Russia, and Belarus were used for the comparative analysis. The results of different investigations published in the reports of international and national official and nongovernmental organizations were also used.

International Climate Change Policy

The international community started to pay special attention to climate change since the mid-1980s of the twentieth century. Scientists all over the world have come to the conclusion that climate change and human activities are linked

(Forrester 1971; Medous et al. 1972; Meadows et al. 1992, 2004; Budyko and Izrael 1991; Report 2002). It also became clear that the problem is very complex, and therefore it is necessary to bring together scientists from all countries to obtain more precise conclusions and forecasts. In 1988 the World Meteorological Organization (WMO) and the United Nation Environmental Programme (UNEP) created the Intergovernmental Panel on Climate Change (IPCC). The global task of IPCC is preparing the regular reports in environmental fields. The first report was published in 1990 (Houghton et al. 1990). In this report IPCC confirmed the threat of climate change due to anthropogenic activity and called to prepare a special global treaty to solve this problem.

The last IPCC (2007) report pointed that "warming of the climate system is unequivocal, as is now evident from the observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level." Considering the reasons of such warming, the authors of the report mention that "Most of the observed increase in global average temperatures since the mid-twentieth century is *very likely* due to the observed increase in anthropogenic GHG concentrations. This is an advance previous conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in GHG concentrations." "It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)."

It is necessary to point that experts are very careful calling the reason of climate change and noting at the same time that "the observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are simulated only by models that include anthropogenic forcing."

Besides that IPCC publishes special reports, methodic reports, technical papers, and supporting materials accessible at IPCC site (https://www.ipcc.ch/publications_and_data/publications_and_data.shtml).

Modeling and scenario tools form the basis of a number of global and regional assessments that project future environments on the basis of changes in drivers of ecosystem change and biodiversity loss according to various development scenarios (IEEP 2009).

Ministry Declaration adopted at 2nd World Climate Conference in Geneva in October–November of 1990 supported the idea of preparing special global agreement on solution to climate change.

United Nations General Assembly in December of 1990 adopted a resolution 45/212 (UN 1990), on the bases of which a special Intergovernmental Negotiating Committee on this problem was formed. As a result of its work, the framework convention was adopted by governments at the 5th session of the committee (UNFCCC 1992). The convention was open to signing at UN Conference in Rio at 1992 and came into force on the March 21, 1994.

At present more than 190 countries are the parties of the convention including Russia and the Republic of Belarus, all industrial countries, countries with transition economy, and most developing countries.

The object of this convention is "to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

UNFCCC maintained the total concept for the realization of international activity directed to solving the problem of climate change. The main goal of this concept is stabilization of GHG concentration at the level that prevents their adverse effect on the climate system.

Convention parties adopted some obligations directed on the solution of the problem of climate change. All countries have to develop and present special reports called national communications. These national communications should have the information about the level of GHG emission and fulfilled and planned actions in the country.

It was clear that the positions of the convention could not solve the problem of climate change and the decision on the expansion of the convention was adopted in Kyoto, Japan, December 1997. Kyoto Protocol (1998) defines the goals on limiting of emission for industrial countries, and the innovation mechanisms were suggested to achieve these goals.

The Kyoto Protocol came into force on February 16, 2005, when 55 parties ratified it. Countries with well-developed industries must reach 95 % level of CO_2 in comparison with its level in 1990. Kyoto mechanisms are:

- International emissions trading. Parties with commitments under the Kyoto Protocol (Annex B Parties) have accepted targets for limiting or reducing emissions. These targets are expressed as levels of allowed emissions, or "assigned amounts," over the 2008–2012 commitment periods. The allowed emissions are divided into "assigned amount units (**AAUs**)."

Emissions trading, as set out in Article 17 of the Kyoto Protocol, allows countries that have emission units to spare – emissions permitted to them but not "used" – to sell this excess capacity to countries that are over their targets. Thus, a new commodity was created in the form of emission reductions or removals. Since carbon dioxide is the principal greenhouse gas, people speak simply of trading in carbon. Carbon is now tracked and traded like any other commodity. This is known as the "carbon market."

- Clean development mechanism (CDM). The clean development mechanism (CDM), defined in Article 12 of the Protocol, allows a country with an emission reduction or emission limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one ton of CO_2, which can be counted toward meeting Kyoto targets.

The mechanism is seen by many as a trailblazer. It is the first global environmental investment and credit scheme of its kind, providing a standardized emission offset instrument, CERs. A CDM project activity might involve, for example, a rural electrification project using solar panels or the installation of more energy-efficient boilers.

The mechanism stimulates sustainable development and emission reductions, while giving industrialized countries some flexibility in their emission reduction or limitation targets.

- Joint implementation (JI). The mechanism known as “joint implementation,” defined in Article 6 of the Kyoto Protocol, allows a country with an emission reduction or limitation commitment under the Kyoto Protocol (Annex B Party) to earn emission reduction units (ERUs) from an emission reduction or emission removal project in another Annex B Party, each equivalent to one ton of CO_2, which can be counted toward meeting its Kyoto target.

Joint implementation offers Parties a flexible and cost-efficient means of fulfilling a part of their Kyoto commitments, while the host Party benefits from foreign investment and technology transfer.

United Nation Environmental Program considers climate change as one of the major challenges of our time (Climate Change 2010) and suggested climate change subprogram for strengthening the ability of countries, particularly developing countries, to integrate climate change responses into national development processes. The subprogram has four key goals:

- Adapting to climate change: UNEP helps countries reduce their vulnerability and use ecosystem services to build natural resilience against the impacts of climate change.
- Mitigating climate change: UNEP supports countries in making sound policy, technology, and investment choices that lead to GHG emission reductions, with a focus on scaling up clean and renewable energy sources, energy efficiency, and energy conservation.
- Reducing emissions from deforestation and forest degradation (REDD) is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. REDD+ goes beyond that to include the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks.
- Enhancing knowledge and communication: UNEP works to improve understanding of climate change science and raise awareness of climate change impacts among decision-makers and other target audiences.

The detailed rules for the implementation of the Kyoto Protocol for developing countries were adopted at the Conference of the Party in Marrakesh, Morocco, in 2001, and are referred to as the “Marrakesh Accords.” Without waiting for the end of the Kyoto Protocol, the Parties to the Kyoto Protocol took part at conferences of the Parties (COP) and discussed problems connected with its realization and extension.

The COP16 took place at Cancun and was hosted by the Government of Mexico. The meeting produced the basis for the most comprehensive and far-reaching international response to climate change the world had ever seen to reduce the carbon emissions and build a system which made all countries accountable to each other for those reductions.

The COP17 took place from November 28 to December 9, 2011, in Durban, South Africa, as a part of the United Nations Climate Change Conference which delivered a breakthrough on the international community response to climate change. Progress was made toward establishing a new international framework in which all states participate.

In Doha, Qatar, on December 8, 2012, the "Doha Amendment to the Kyoto Protocol" was adopted. The amendment includes (Doha 2012):

- New commitments for Annex I Parties to the Kyoto Protocol which agreed to take on commitments in a second commitment period from January 1, 2013, to December 31, 2020
- A revised list of greenhouse gases (GHG) to be reported on by Parties in the second commitment period
- Amendments to several articles of the Kyoto Protocol which specifically referenced issues pertaining to the first commitment period and which needed to be updated for the second commitment period

On December 21, 2012, the amendment was circulated by the Secretary-General of the United Nations, acting in his capacity as Depositary, to all Parties to the Kyoto Protocol in accordance with Articles 20 and 21 of the Protocol.

The 19th session of the Conference of the Parties to the UNFCCC and the 9th session of the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol will take place from November 11 to 22, 2013. The conference will be held in Warsaw, Poland.

During the first commitment period 37 industrialized countries and the European Community committed to reduce the GHG emissions to an average of five percent against 1990 levels. During the second commitment period, Parties committed to reduce GHG emissions by at least 18 percent below 1990 levels in the eight-year period from 2013 to 2020; however, the composition of Parties in the second commitment period is different from the first (Doha 2012).

Russia and Climate Change

Russia ratified UNFCCC in 1994 and Kyoto Protocol in 2004 году. As a result Kyoto Protocol entered into force for all its parties. The main goal of Russia in accordance with Kyoto Protocol was not to overcome the average level of emission of GHG in the period 2008–2012 years against 1990. In spite of the intensive economy growth, the common level of anthropogenic emissions of GHG in Russia at present time is less than in 1990.

Commitment period of the Kyoto Protocol was established within the period of 2008–2012. In the Federal Law (2004), Russia declared that its participation in the second period of commitments would be decided separately and depend on the progress of the international negotiations, on international agreements, and on its understanding what measures should be taken to prevent global environmental challenge. In the communication dated December 8, 2010, and sent to the secretariat of the UNFCCC on December 9, 2010, the Russian Federation indicated that it did not intend to assume a quantitative emission limitation for the second commitment period.

In accordance with UNFCCC and Kyoto Protocol, Russia develops its national policy on preventing the climate changes and their negative consequences, on limitation and reduction of anthropogenic emissions, and on increase of GHG.

Kyoto Protocol and UNFCCC provided the following conditions necessary for participation at Kyoto mechanisms:

- Fulfillment of quantitative obligations on emission reduction
- Adoption of National Action Plan and measures for reduction of GHG emissions in accordance with the quantitative commitments
- Creation of National system of accounting of GHG emissions and discharges
- Organizing the National register of the accounting units of GHG emissions
- Establishment of a quantitative value carbon credits on the basis of the inventory data in 1990
- Reporting to the UNFCCC secretariat in the form of national communications
- Examination of reports by international team of experts, etc.
- Development of National Climate Change Policy
- Creation of national system of monitoring of GHG emission

Action plan (2005) for the realization of the Kyoto Protocol in Russia was adopted on July 15, 2005. Plan involved four sections. The first section included measures for reduction of GHG emission in different sectors of economy. The second was dedicated to the creation of national system of inventory of GHG emissions and their removal by forests. Economic mechanisms of the Kyoto Protocol were considered in the third section. International activity and negotiation process on the following international convention were discussed in the fourth section.

Starting from 2007 different legislation acts aimed at the further realization of the measures for mitigation of climate change and adaptation to climate change have been adopted:

- Decree of the President of Russia of June 4, 2008, № 889 “On some measures to improve the energy and environmental efficiency of the Russian economy”
- The concept of long-term socioeconomic development of the Russian Federation until 2020
- Russian Government Resolution № 1-r of January 8, 2009, “On the main directions of the state policy in the sphere of electrical energy efficiency from renewable energy sources till 2020”

- The program of anti-crisis measures of the Government of the Russian Federation in 2009
- Federal Law of November, 2009, “On energy saving and energy efficiency”
- “Climate Doctrine of the Russian Federation” of December 17, 2009
- “The Energy strategy of Russia until 2020”
- “Action plan for realization of Climate Doctrine” of April 25, 2011

All these documents contain regulations concerning the conditions of realization of the Kyoto Protocol. Climate Doctrine (2009) is based on fundamental and applied scientific knowledge about climate and related areas:

- Assessment of the past and the current state of climate system
- Assessment of the factors of the influence of anthropogenic activity on climate
- The forecast of the possible climate changes and their influence on the quality of life of people in Russia and other regions
- Assessment of the security and vulnerability of ecosystems, economy, population, governmental institutions, and infrastructure of the state in relation to climate change and adaptation of the existing facilities to climate change
- Assessment of the possibilities to mitigate human impacts on climate

Action plan (2011) for the realization of Climate Doctrine considers all measures and organizations to achieve the goals.

Fundamental principles of the Russian climate change policy are (Communication 2010) as follows:

- Global feature of Russian interest in climate change and its consequences
- National interest priority in the development and realization of climate policy
- Clarity and availability of the information on climate policy
- Recognition of the need for actions, both within the country and as a part of the full international partnership of the Russian Federation in international research programs and projects relating to climate change
- A comprehensive account of the possible losses and gains due to climate change
- Precaution in the planning and implementation of measures to ensure the security of the person, the economy, and the state from the adverse effects of climate change

From 1990 to 1998 there was a decline in emissions, affecting all sectors, it related with the dynamics of the economic situation in the country in the Russian Federation. Later, during the period of economic growth, there was a steady increase in emissions. In 2011, total GHG emission was by 16.3 % higher against 1998, but remained 30.8 % against 1990 emissions (Report 2013).

Decline in GHG emission in Russia directly depends on the energy strategy. At present the energy consumption of Russian economy 2.3 times greater than the average world index on the average and 3.2 times greater than EU indexes (Climate Change 2012).

Climate doctrine (2009) considers the increase of energy efficiency in all sectors of economy and the development of renewable and alternative energy sources ad priority direction of the development.

In accordance with Kyoto Protocol, Russia could take part in all mechanisms of protocol. But actually Russia did not realize this opportunity.

Analyzing the use of flexible mechanism under the Kyoto Protocol, Gromova (2011) demonstrated inefficiency of the existing system of implementation of the emissions trading, clean development mechanism (CDM), and joint implementation (JI) in Russia. The procedure of taking decision on the presented projects is very complicated and need to be improved. At the end of July 2010, the first 15 JI projects were with CO_2 equivalent reduction about 30 million tons. In November 2010 the expertise of 58 projects with 75.6 million tons of CO_2 equivalent was fulfilled.

The program "Climate and Energy" of WWF is aimed at the decrease of global emission of CO_2 and other GHG and at the timely assistance to adaptation of ecosystems to climate change. From 2011 WWF started the "green" development of energy directed at technological modernization of Russia.

Some large Russian companies adopted their own program of energy saving and resource economy:

- Corporation "Gazprom" estimated GHG emission at their enterprises and created an emission register.
- Oil company "Lukoil" adopted the corporative conception and activity plan on the bases of the Kyoto Protocol.
- Company "Norilski Nikel" estimated GHG emission in its Polar division and developed "Information analytical system making inventory and monitoring GHG," the forecast of emissions till 2015 was fulfilled.

Belarus and Climate Change

Climate change is a complex problem, which, although environmental in nature, has the consequences in all spheres of existence on our planet. Belarus shares global concerns on the impact of climate change and supports international efforts on reducing carbon emissions. The norms of international agreements in the field of climate change act in Belarus are the following:

- United Nation Framework Convention on climate change was signed on June 12, 1992, at the UN conference in Rio de Janeiro and was approved on April 10, 2000, by the President of the Republic of Belarus.
- Kyoto Protocol to UNFCCC. The Republic of Belarus joined it in 2005 in accordance with the Decree of the President of the Republic of Belarus.

At present the Republic of Belarus has well-developed legal system with a remarkable number of the subordinate laws which may be found at site (www.minpriroda.by).

The law “On environmental protection” is the basic environmental law. This law defines principles and goals of environmental protection, objects and parties involved in environmental protection.

The law “On atmospheric air protection” is directed at the conservation and improvement of the quality of atmospheric air.

Joining the Republic of Belarus to UNFCCC and Kyoto Protocol involves the adoption of legal acts regulating the relations in the field of GHG emissions and the rights on GHG emissions. Some of such acts are as follows:

- The Resolution of the Council of Ministers of the Republic of Belarus of December 30, 2005, No 1582 “On realization of norms of the Kyoto Protocol to UNFCCC.” This Resolution adopted the action plan on realization of norms of the Kyoto Protocol to UNFCCC for 2005–2012.
- The Resolution of the Council of Ministers of the Republic of Belarus of April 10, 2006, “On State cadastre of anthropogenic emissions of GHG from sources and their removal by sinks.”
- The Resolution of the Council of Ministers of the Republic of Belarus of August 25, 2006, No 1077 “On National register of carbon units of the Republic of Belarus.”
- The Resolution of the Council of Ministers of the Republic of Belarus of September 7, 2006, No 1155 “On the Strategy of decreasing of emissions of GHG and their removal by sinks in the Republic of Belarus in 2007–2012.”
- The resolution of the Council of Ministers of the Republic of Belarus of August 4, 2008, No 1117 “On the National programme of measures on mitigation of climate change in 2008–2012.”

It is seen that the Republic of Belarus has fulfilled its obligations on UNFCCC and Kyoto Protocol. Institutional and legal bases were created to take part in the flexible mechanism of the Kyoto Protocol. “Strategy of decreasing of emissions of GHG and their removal by sinks in the Republic of Belarus in 2007–2012” and “The National programme of measures on mitigation of climate change in 2008–2012” were adopted. National system of GHG inventory was also developed. The Republic of Belarus regularly presents National Communications under the United Nations Framework Convention on Climate Change.

The Fifth National Communication (2009) contains the results of implementation of the UNFCCC and Kyoto Protocol from 2006 up to 2009 and includes the information on national circumstances, generalized data on inventory of the GHG emissions and their removals in sectors of energy, industry, agriculture, land use change and forestry, waste, policies and measures on decrease in GHG emissions and their forecast indicators, the assessment of vulnerability and adaptation of the national economy to climate change; data on newly adopted normative and legal documents in the country; data on the National Registry of Carbon Units; and information on current R&D facilitating to reduce GHG emissions and prevent their impact on climate change.

The analysis of various projection scenarios of GHG emission reduction shows that Belarus has exhausted the potential of relatively low-cost actions for the reduction of these emissions. Any other emission reduction measures as well as the mechanisms to support environmentally sensitive actions require substantial investment of funds which are not available in the country, specifically in the crisis situation. It was expected that the resources the country needs could be partially raised by selling available emission quotas in 2008–2012.

There is a national procedure defined by legislation act to approve the project directed at decreasing of GHG emission. Some projects were approved, but their realization will be possible when Belarus gets access to flexible mechanism under the Kyoto Protocol.

Nevertheless there is an activity on preparing and realization of the volunteer projects directed at the reduction of the GHG emission. One of such projects is "Restoration of peat lands."

The fact that the amendment of the Republic of Belarus to the Annex B to the Kyoto Protocol stipulating quantitative obligations and providing the opportunities for using flexible mechanisms has not been ratified by the required number of the Parties to the Kyoto Protocol (only 26 Parties from 141 needed) poses an obstruction to this.

It is expected that Belarus will be a party of the second commitment period of the Protocol. It can help Belarus to fix its obligations and present the possibility to use the flexibility mechanisms of the Kyoto Protocol. But at the consultations held in Minsk on January 21–22, 2013, with the participation of the representatives of public authorities and experts from Belarus, Russia, Ukraine, and Kazakhstan, the sides postponed the ratification of the Doha amendment to Kyoto Protocol, regulating the second commitment period of the Kyoto Protocol, at least until the end of 2013.

Belarus continues its work on the reduction of climate change. New "State programme of measures directed at mitigation of climate change consequences in 2013–2020" was adopted by the government decree on June 21, 2013, № 510. As the previous program, it is aimed at:

- Realization of measures on fuel and energy economy in energy sector
- Stabilization of the level of GHG emissions due the use of resource saving technologies in energy-consuming sectors of economics
- Optimization of waste management
- Improving of the quality and increase of the volume of GHG absorbers

The Climate Change Performance Index

The analysis of the results presented in the Climate Change Performance Index (CCPI 2013) shows that the climate policies of Russia as well as Belarus are estimated negatively. Russia dropped to 56th position of 61 participants and Belarus dropped to 35th position (it lost 8 positions). This data was calculated on the statistics of 2010 and the use of the performance indices – the level of emissions, the development of emissions, renewable energy, and climate policy. All these performance indices for Russia were found as very poor, whereas the performance indices for Belarus were at moderate and poor levels.

Conclusion

Up to the present, the Kyoto Protocol is the only international legal document that at least to some extent regulates the global climate change and the reduction of GHG emissions. The new agreement will start working only in 10 years; it is unknown if it is going to be efficient.

Note that the withdrawal of Canada from the Kyoto Protocol and refusal of Japan and Russia to take any obligations on the second commitment period lead to the loss of status of the protocol. The USA and China are not the parties of the protocol. These countries produce the greatest amount of emissions.

At the same time the developed countries make considerable efforts to decrease the level of emissions. The data in *The Wall Street Journal* presented on the site (http://bin.ua/news/economics/faec/140951-ssha-otkazavshiesya-podpisat-kiotskij-protokol.html) indicated that in 2011 against 2005 China, India, and Russia showed the increase of emissions, but Japan, Canada, Germany, Great Britain, and EU as a whole showed the decrease of emissions; the most significant progress in decreasing of emissions was being demonstrated by the USA.

If Russia and Belarus do not join the second commitment period, their companies will no longer be able to benefit from carbon market. They will not get investments for modernization and reconstruction of enterprises, for creation of new high technological enterprises. As a consequence the competition of Russian and Belarusian producers will fall.

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Linkage of Agricultural Productivity Improvement and Climate Mitigation Action in Africa

Labintan Adeniyi Constant and Harald Winkler

Contents

Abstract

This study explores the relations between agricultural productivity improvement and mitigation potentiality in Africa mainly in Ghana, Kenya, Rwanda, and Zambia characterized by different agricultural production system and agroecological zones.

Firstly it used Decomposition of Productivity Number Index approach to evaluate the country's agricultural productivity during their pre- and post-economic market openness. Secondly, the country's agriculture, forestry, and other land use (AFOLU) emission is assessed, while the last part uses robust regression to determine their impact on country's agricultural productivity.

It is found that agricultural productivity is improved relatively during the country's post-economy liberalization. Annual agriculture emission is higher in Kenya with relative annual changes, while changes in forest land emission are considerably in Rwanda. The regression analysis showed that an increase in agricultural emission contributes to a relative decrease in, respectively, Ghana, Rwanda, and Zambia agricultural performance. This means a decrease in their

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agricultural productivity. However, agricultural emission is contributing to improvement of Kenya agricultural performance. This means an increase in Kenya's agricultural productivity. Furthermore, forest land sink has positive implication of agricultural productivity in Rwanda. Forest land therefore is contributing to an improvement of Rwanda agriculture production performance. In addition, there is no significant impact of land use change emission on the selected countries' agricultural performance.

Finally, this chapter found that under the selected country's production system, their goal of improving their agricultural sector performance by 6 % toward 2015 will reduce Ghana agriculture emission intensity, transform Zambia in agriculture carbon neutral country, increase Rwanda forestry sink potentiality, and increase Kenya agriculture net emission intensity.

This chapter highlights on the need to investigate the linkage on case-by-case basis due to the difference in the country's agricultural system and agroecological zones, while the cost of mitigation will constitute an important indicator in decision making.

Keywords

Agricultural productivity • GHG emission • Mitigation • Africa

Introduction

Agricultural sector in Africa is a key source of economic growth and a large source of foreign exchange, saving, and tax revenue. It contributes to over 40 % of currency earning, feeds and generates income for low-income household, and alleviates poverty. Despite several agricultural reforms undertaken in African countries, the gap between the sector supply and the demand is still very high. The sector is characterized by low productivity, high production cost, low mechanization, intensive labor use, limitation in credit accessibility, and market accessibility difficulties. Furthermore, it is estimated that the region population will rise from 770 million to 2 billion by 2050 (FAO 2009) which will significantly increase the agricultural demand.

Moreover, increase in climate change extreme events frequency such as drought and flood increased more pressure on agricultural inputs accessibilities such as water and arable land. This is likely to result in a decrease of the sector production yield. A recent study in assessing the impact of climate change on agricultural productivity reveals that average cereal yield in sub-Saharan Africa will decrease at 3.2 % in 2050 (Nelson et al. 2009; Ringler et al. 2010) with an aggregate decrease in yield, respectively, of 17 %, 5 %, 15 %, and 10 % of wheat, maize, sorghum, and millet (Knox et al. 2012). This will affect the region's food availability and increase the vulnerability of low-income households.

The agricultural sector including crop and livestock production, forestry, and associated land use changes are also identified to be major sources of greenhouse gas (GHG) in Africa and in addition has great sink potentiality (IPCC 2006). It has been estimated that in sub-Saharan Africa, over 43 % of the total CO_2 emissions originate from land clearing from agricultural use and a further 316 billion tons of CO_2 eq is stored in top soils at risk from degradation (Gledhill et al. 2011). According to IPCC (2006) the sector's major emission sources are enteric fermentation (natural digestive process in ruminant animal), manure (manure management, manure applied to soil, and manure left on pasture), synthetic fertilizers, rice cultivation, crop residues, cultivated organic soil, and CO_2 emission from burning crop residues, forest, and land use.

Indeed, the trade-offs between agricultural growth and GHG emission intensity in Africa have been recognized by scholars and policy makers; however, more efforts were allocated to adaption strategies instead of mitigation actions. The mitigation matter started after COP15 in Copenhagen in 2009 where non-Annex 1 parties were invited to submit their "Nationally Appropriate Mitigations Actions" in order to ensure "sustainable development." Therefore, the concern about mitigation of climate change in the agricultural sector grew in Africa.

Climate change mitigation action in the agricultural sector will have co-benefit effects for the sector. On one hand, they will improve the sector inputs efficiency. Sustainable land management (SLM) practices will contribute to mitigating climate change in sub-Saharan Africa, by sequestering carbon in soils and vegetation (sink potentiality), reducing emissions of greenhouse gases (carbon dioxide, methane, and nitrous oxide), and reducing the use of fossil fuel and agrochemicals (Woodfine 2010). This will improve land resource resilience and productivity by maintaining long-term productivity and ecosystem functions (land, water, biodiversity) and increase productivity (quality, quantity, and diversity) of goods and services (including safe and healthy food). On the other hand, SLM practices will offer smallholder's opportunities to reduce the need for labor, capital- and fuel-intensive land preparation, and tillage. This can constitute a very good agricultural financing opportunity in Africa through carbon trade system and improve rural household development (Shames et al. 2012; Winston et al. 2012; Byamukama et al. 2012; Masiga et al. 2012).

Although the African agricultural sector present an important potential of mitigation, very limited research does quantify the mitigation level, the cost of possible mitigation actions in the region agricultural sector, and how mitigation action will influence the country's agricultural development policy goals and vice versa. The region's key agricultural development policies include the Comprehensive Africa Agriculture Development Programme (CAADP) launched in 2003. The policy aims to boost African country's agricultural annual productivity performance by 6 %, enhancing economic growth, eliminate hunger, and reduce poverty through sustainable agricultural production practices and intensive investment (NEPAD-CAADP 2010). This includes sustainable and efficient agricultural input such as land and water resources management. The policy may have some implication on the region climate change mitigation policy option. This chapter then explores the contribution of country's agricultural productivity improvement policies in mitigating climate change in African countries. This means assessing the contribution of agricultural productivity improvement to carbon dioxide equivalent GHG emission abatement and the associated cost. It highlights policy maker on appropriate actions to yield the sector sustainable development policy goal.

Theoretical Approach of Agricultural Productivity Assessment

Chambers (1988) defined the concept of productivity measurement as an approach to assess the production rate of technical change. He emphasized that firm productivity is conceptualized by two main components. The first component is partial factor of productivity (PFP) which is the ratio of firm total output Q_i and any m_i input used to produce that output. The second component is the total factor of productivity (TFP) which is the firm total output Q_i ratio with summation of all input $x_{i.}$

Indeed, Farrell (1957) following Debreu (1951) and Koopmans (1951) analyzed difference in performance of firms which yield each a given quantity of output (oriented output) using a certain amount of inputs. They found that difference in the firm's productivity is explained by their ability to produce the given amount of output using minimal input (technical efficiency) and economics scale. The last term is the firm's allocation efficiency of producing a maximum quantity of output using an optimum input. Taken into account technological progress, the technical efficiency change will also contribute to their productivity component (to their performance). This is illustrated in Fig. 1 where x_{ns} is the quantity of input use to

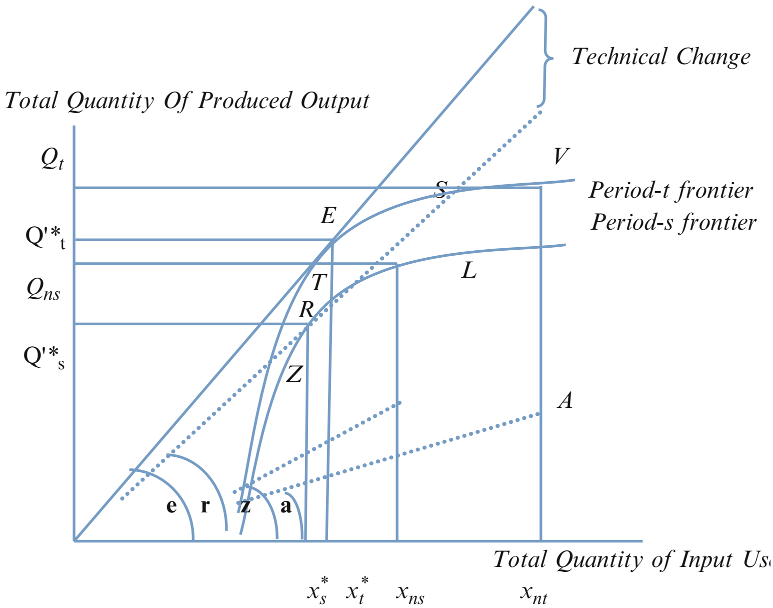

Fig. 1 Decomposition of firm production performance using respectively technology s and t (Source: author own composition)

produce and Q_{ns} quantity of output during the first period using technology s. Using the same technology s, x_s^* is the minimum input required to produce an optimal quantity of output Q_s^*. When the firm production technology changed to new technology t during the second period, x_{nt} is the quantity of input used to produce a given quantity of output Q_t. Notwithstanding, under the new technology, x_t^* is the minimum quantity of input required to produce an optimal level of output Q_t^*.

However, Balk (2001) argues that firm productivity is not only explained by technical change and economics scale. He concludes that output mix effect could also influence firm productivity. This means the combination of firm's given producing total output. Similar conclusion has been made by Coelli et al. (2005) and O'Donnell (2010). This is illustrated in Fig. 2.

Nonetheless, it is common to assess firm's production performance for a given time period using these approach and investigate explanatory exogenous driving factors of difference in yield performance. This is essential to investigate why a firm performs differently within one period or across period. However, nowadays, the concern of climate change and introduction of climate change mitigation policy could also considerably influence the firm's performance in agriculture sector; the concern on the sector contribution to GHG emission and goal of improving agricultural productivity raise interest to explore how mitigation policies could influence this goal in Africa. But how could this be investigated?

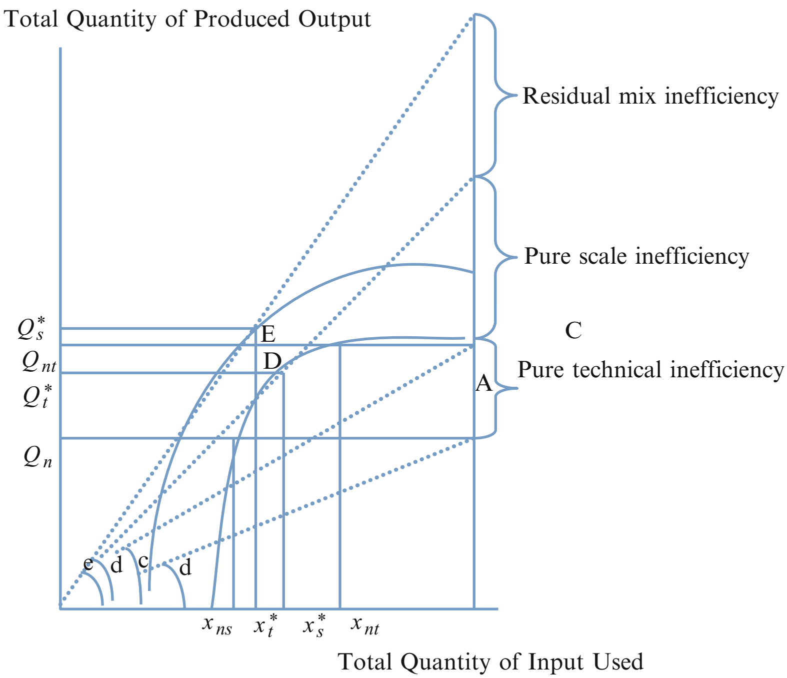

Fig. 2 Robust decomposition of firm production performance under respectively technology s and t (Sources: author own composition)

Agricultural Productivity Driving Factor and Mitigation Potential

Most studies which evaluate agricultural productivity improvement conclude that agricultural research (Ruttan 1996; Chang and Zepeda 2001), agricultural extension, agricultural infrastructure (Evenson and Pray 1991; Antonio and Robert 2001; Evenson 2000), resources allocation (Jorgenson 1988), climate change, and government effectiveness are major driving factors of agricultural productivity (Sharmistha and Richard 2006; Mandemaker et al. 2011).

However, unlike climate change, a change indicator which can contribute to an increase or a decrease in productivity, most studies emphasize extreme events such as drought or flow. Usually, rainfall is the proxy used for drought or flow. This leads more to adaptation strategy to control drought and flood in order to reduce their effect on agricultural crop productivity (You and Ringler 2010). Moreover, uncertainties in rainfall used as drought or flood proxy reveal the difficulty of using this approach (Jemma et al. 2010).

Perhaps, a recent study emphasizes that emission reduction from agricultural sector present great potential for agricultural productivity improvement (Pete Smit et al. 2008; Capper 2011; Baker et al. 2012; Gerber et al 2013).

Capper (2011) in analyzing mitigation in livestock sector argues that improving productivity has considerably reduced the carbon footprint of dairy and beef production and its share by consumers is extensive, when traditional systems have a lower carbon footprint.

Pete Smit et al (2008), by exploring GHG mitigation potential in agriculture sector, conclude that agricultural practices can potentially mitigate greenhouse gas (GHG) emissions which will contribute to improving land productivity. This includes improving cropland and grazing land management and restoration of degraded lands and cultivated organic soils with high potential, while water and rice management, set aside, land use change and agroforestry, livestock management, and manure management have low potential.

Baker et al. (2012), by assessing US agricultural productivity growth contribution to mitigation potential with focus on land management, found that lower crop and livestock productivity growth leads to higher emissions from land use change and management, while lower emissions from livestock operations has a minimal net impact on aggregate emissions.

Indeed, Bryan et al. (2011) evaluated the linkage between agricultural productivity and mitigation potential in Kenya at a small-scale level and found that small-scale mitigation action thought integrated soil fertility management and soil water conservation has contributed to the improvement of crop productivity in Kenya.

Recent developments show that an adoption of climate smart practices will contribute to achieve emission target in the agriculture sector (World Bank 2011) and could also affect the sector productivity. This will be achieved through sustainable farming practices contribution to land fertility and water. However, very limited research does investigate how AFOLU emission intensity can also affect the agricultural sector through their direct impact. This constitutes another exogenous factor which may be a robust proxy than annual rainfall accounting.

Methodology and Data Sources

*S*ample: The study considers four African countries, namely, Ghana, Kenya, Rwanda, and Zambia where agricultural sector account for, respectively, 26 %, 28 %, 32 %, and 20 % of their GDP (WRI 2013). Among different economic reforms undertaken in those countries as in most African countries, the agricultural sector has been fundamental. Indeed, in 1990 their agricultural sector was liberalized in order to stimulate the sector competitiveness and create good private investment climate. This also has included improvement of their land policies. This contributes to increase in their agricultural production and their exportation. However, the intensification of their agricultural production contributes differently to each country's agriculture, forestry, and other land use emission typology.

The first part then assesses their agricultural productivity, profitability, and changes in their production abilities. It applied the decomposition of Productivity Index Number proposed by O'Donnell (2010) to assess selected countries' total productivity factor (TFP), profitability (PROF), and term of trade (TT). The TFP is the appropriate indicator which quantifies their agricultural production performance or frontier, while the PROF measures their agricultural sector profitability which depends on their production cost and their production output cost. However, the TT indicate the ratio between country exported output price and imported output price.

Simulation is done using DPIN software. Inputs and outputs agricultural data have been collected from FAO database, Ghana Ministry of Food and Agriculture (MOFA), Kenya Ministry of Agriculture, Rwanda Ministry of Agriculture and Animal Resources, Zambia Ministry of Agricultural and Livestock Agricultural Science and Technology (ASTI).

Land: Arable land and permanent crop area (ha)
Labor: Economically active population in agricultural sector (man/ha)
Fertilizer: Amount of fertilizer and herbicide used (kg/ha)
Seed: Planted material (kg/ha)
Agricultural machine: Total agricultural machine and tractor used per 100 m^2
Crop: Aggregated major crop production (kg/ha)
Vegetable: Aggregated vegetable and fruit production (kg/ha)
Cash crop: Aggregated major cash crop production (kg/ha)

Due to limitation in prices data availability, input and output prices on 2008 have been used. Statistical descriptions of the input and output data used are presented in Tables 1, 2, 3, and 4 below.

The second part access their figure of AFOLU emission intensity per ha. Emission data is collected from FAO statistical database.

The third part evaluates the effect of AFOLU emission on selected countries' agricultural productivity using two-stage Data Envelopment Analysis (DEA) approach. However, the two-stage results can suffer from correlation error between input variables used in the first stage when assessing firm performance and

Table 1 Summary of agricultural inputs-outputs in Ghana

Variable	Number of observation	Mean	Standard deviation	Minimum	Maximum
Grain (kg/ha)	45	2316.464	916.1159	1171.769	4793.525
Vegetable (kg/ha)	45	709.5128	181.5059	421.8656	1116.542
Livestock (kg/ha)	45	1029.185	573.8502	404.8069	2230.692
Cash crop (kg/ha)	45	654.1043	160.4685	422.1081	974.9874
Land (ha)	45	3,186,133	1,100,011	1,700,000	4,700,000
Labor (man-day/ha)	45	1.223616	0.17456	0.993947	1.607059
Fertilizer (kg/ha)	45	1.279142	0.465231	0.77	3.217391
Machine (tractor/ha)	45	0.412761	0.928791	0.000944	3.306134
Seed (kg/ha)	45	135.9314	21.13657	113.3871	186.9893

Sources: author own composition based on FAO statistical database

Table 2 Summary of agricultural inputs-outputs in Kenya

Variable	Number of observation	Mean	Standard deviation	Minimum	Maximum
Grain (kg/ha)	45	2.707777	0.555002	1.634514	3.88598
Vegetable (kg/ha)	45	2.899466	0.630181	1.724518	4.165102
Livestock (kg/ha)	45	4.23476	10.01279	1.456301	69.76406
Cash crop (kg/ha)	45	7.626318	2.32105	4.689775	16.56608
Land (ha)	45	3,964,365	645518.6	2,890,922	5,562,561
Labor (man-day/ha)	45	2.927053	0.352239	2.277508	3.848183
Fertilizer (kg/ha)	45	0.024941	0.008803	0.010526	0.04019
Machine (tractor/ha)	45	0.002677	0.001035	0.001733	0.00876
Seed (kg/ha)	45	0.000706	0.000121	0.000497	0.000938

Sources: author own composition based on FAO statistical database

explanatory variables used in the second stage when assessing firm performance driving factors (Wilson 2003; Simar and Wilson 2007). An alternative approach was proposed by Simar and Wilson (2007), who developed single and double bootstrap procedures to reduce the drawbacks. Their approach also allows the second-stage regression to be estimated and inferences to be made using robust logit regression method. This is done using Stata11.

The regression formula is explicit as follows:

$$Ln(TFP) = c + \alpha \ln(Agriex) + \beta \ln(R\&D) + \varphi \ln(Goveff) + \delta_o \ln(Land)$$
$$+\delta_1 (Labor) + \phi \ln(A) + \gamma \ln(Fo) + \lambda \ln(Lu) + \varepsilon$$

Where c is constant coefficient and α, β, φ, δ_0, δ_1, ϕ, γ, λ are elasticity of explanatory variables driving factors of the agricultural productivity. ε is the term of random error.

Table 3 Summary of agricultural inputs-outputs Rwanda

Variable	Number of observation	Mean	Standard deviation	Minimum	Maximum
Grain (kg/ha)	45	193.8665	145.3263	80.50747	716.3804
Vegetable (kg/ha)	45	175.9184	124.3971	67.57427	604.8115
Livestock (kg/ha)	45	160.194	119.5598	66.13531	594.1937
Cash crop (kg/ha)	45	87.35256	66.52187	36.44341	295.893
Land (ha)	45	3.37E + 07	1.25E + 07	6,324,502	5.50E + 07
Labor (man/day/ha)	45	0.000301	0.000236	0.00015	0.000962
Machine (tractor/ha)	45	0.041725	0.067029	0.002654	0.449412
Fertilizer (kg/ha)	45	3.01E-06	3.00E-06	1.09E-06	0.000013
Seed (kg/ha)	45	0.213096	0.209604	0.088782	0.862426

Sources: author own composition based on FAO statistical database

Table 4 Summary of agricultural inputs-outputs in Zambia

Variable	Number of observation	Mean	Standard deviation	Minimum	Maximum
Grain (kg/ha)	45	12019.81	4119.331	1539.036	21374.53
Vegetable (kg/ha)	45	11346.91	3953.428	1526.518	18114.82
Livestock (kg/ha)	45	1240.849	369.9031	605.7938	1837.185
Cash crop (kg/ha)	45	9236.526	4569.216	1116.385	17306.37
Land (ha)	45	2,765,822	282034.7	2,213,000	3,700,000
Labor (man/day/ha)	45	0.760114	0.186121	0.484641	1.069713
Fertilizer (kg/ha)	45	307.6056	610.9167	22.80398	2566.615
Machine (tractor/ha)	45	0.00206	0.00106	0.000707	0.008248
Seed (kg/ha)	45	11.49622	2.556435	6.755079	14.40485

Sources: author own composition based on FAO statistical database

Agriex is the number of agricultural research staff; R&D means the expenditure for agricultural R&D. These data have been collected from Agricultural Science and Technology Indicator database.

GOVEFF quantifies government effectiveness. This data is collected from the United Nation Conference on Trade and Development (UNCTAD) statistical database.

Land, labor, and AFOLU emission data are collected from FAO statistical database.

The last part concludes and gives some recommendations.

Result and Discussion

Analysis of crop land use emissions across those four countries reveals that between 1990 and 2010 land use, net emission has been relatively much higher with relative change over a year in Zambia and in Rwanda with an average of 0.065 Gg CO_2 eq. which is lower in Ghana and Kenya. This is illustrated in Fig. 3 below.

Analysis of forest land net emission reveals that forest land emission is much important in Kenya, Ghana, and Zambia over the period 1990–2010. However, after 2010 forest land net emission/removal has been negative in Rwanda. This is illustrated in Fig. 4 below.

However, emission from agriculture is much important in Kenya with an average of 0.056 Gg CO_2 eq./Ha and much lower in Ghana, Rwanda, and Zambia. This is illustrated in Fig. 5 below.

From AFOLU emission perspective, it can be concluded that emission level varied considerably between sources and within countries. Land use emission did not change significantly after the agricultural sector market openness, while high land use emission is observed in Zambia. Similar for forest land net emission, while forest land sink potential increased in Rwanda. Furthermore, agriculture emissions varied considerably in Kenya which is the higher agriculture emitter among these countries.

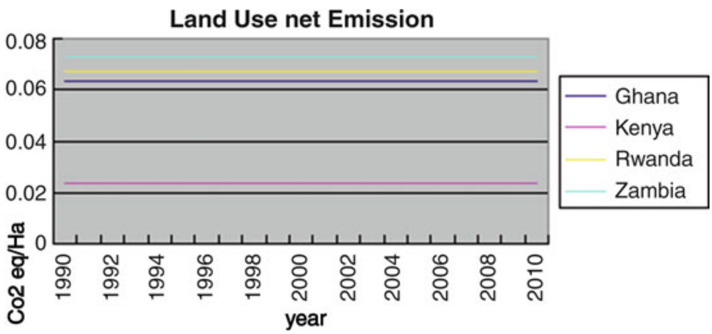

Fig. 3 Crop land CO_2 eq. net emission variation in selected countries between 1990 and 2010 (Sources: author own composition based on FAO emission database)

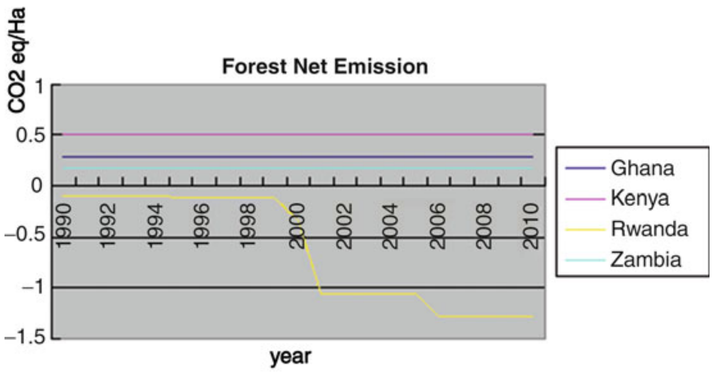

Fig. 4 Forest land CO_2 eq. net emission variation in selected countries between 1990 and 2010 (Sources: author own composition based on FAO emission database)

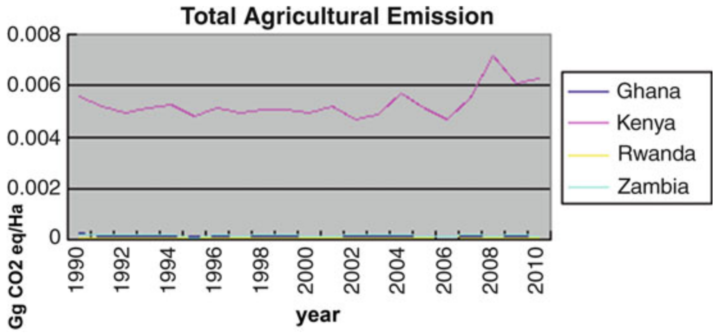

Fig. 5 Agricultural land CO_2 eq. emission in selected countries between 1990 and 2010 (Sources: author own composition based on FAO emission database)

Analysis of agricultural productivity, profitability, and term of trade reveal that:

In Ghana, before the agricultural market liberalization, there is a decrease in the country's agricultural productivity by 46 %. This follows an increase by 46 % after the sector liberalization. While within the same period, there is a net increase by 197 % in the sector profitability. Similarly, there is a net increase in the sector term of trade by 196 %. This is illustrated in Fig. 6a below. However, this performance has been achieved with relatively low change in input technical change efficiency and significant change in input mix efficiency while input scale efficiency does not change. This is illustrated by the Fig. 6b below.

In Kenya, during the reference period, there is a net increase in agricultural productivity by 23.4 %. The net increase in country agriculture profitability is 100 %. Similarly the net increase in the sector term of trade is 39 %. This is illustrated in Fig. 7a. However, a change in inputs scale efficiency is not significant while there is relative change in input scale mix efficiency and input technical change efficiency. This is illustrated in Fig. 7b below.

In Rwanda, during the considered period, the net increase in agricultural productivity is 13.4 %, while there is net decrease in the sector profitability by 95 %. Similarly the net decrease in the sector term of trade is 148 %. This is illustrated in Fig. 8a. However, analysis of inputs efficiency reveals that there are no significant changes in inputs scale efficiency while input mix efficiency does change considerably with relatively lower changes in the country's inputs technical change. This is illustrated in Fig. 8b.

Finally in Zambia, agricultural productivity increased by 69.9 % before 1990 and increased by 16.4 % after, while the profitability has increased by 2.1 before 1990 and decreased by 0.6 after the liberalization. The term of trade decreased over the period with 1.18 decreases before 1990 and 1.13 decreases after. This is illustrated in Fig. 9a. However, analysis of oriented input efficiency reveal relative change in input technical changes over the period and significant change in inputs mix efficiency before the agricultural sector market openness while this

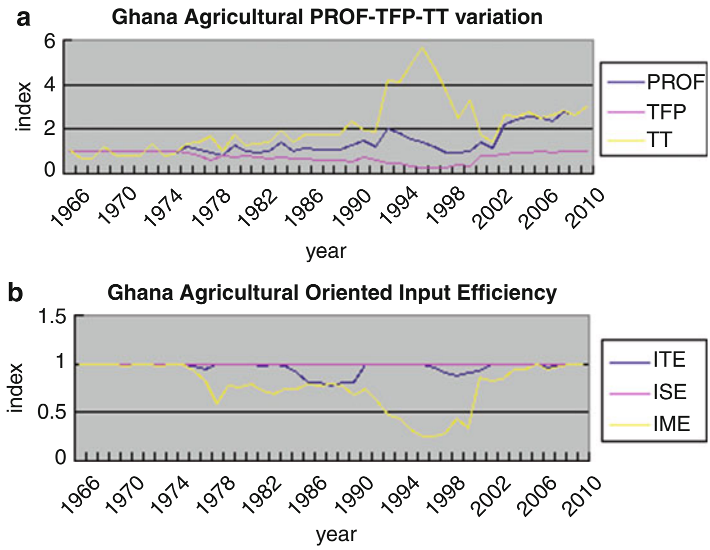

Fig. 6 (**a**) Ghana agricultural productivity profitability and term-of-trade variation between 1965 and 2010. (**b**) Ghana agricultural oriented inputs efficiency variation between 1965 and 2010 (Sources: author own composition based on FAO emission database)

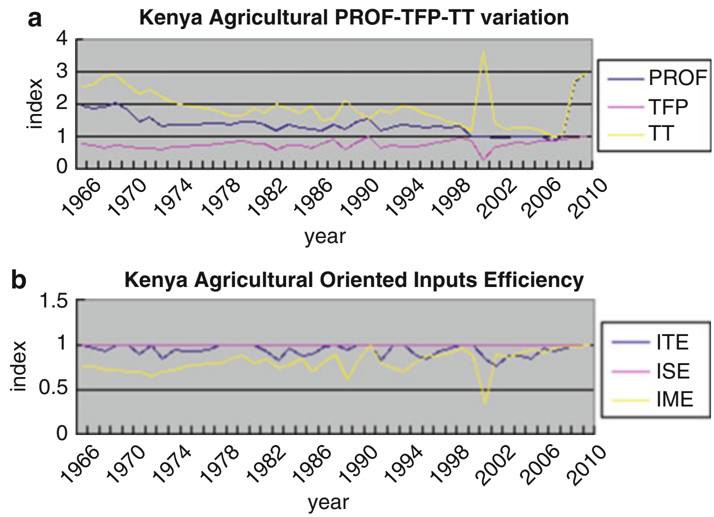

Fig. 7 (**a**, **b**) Kenya agricultural oriented inputs efficiency variation between 1965 and 2010 (Sources: author own composition based on FAO emission database)

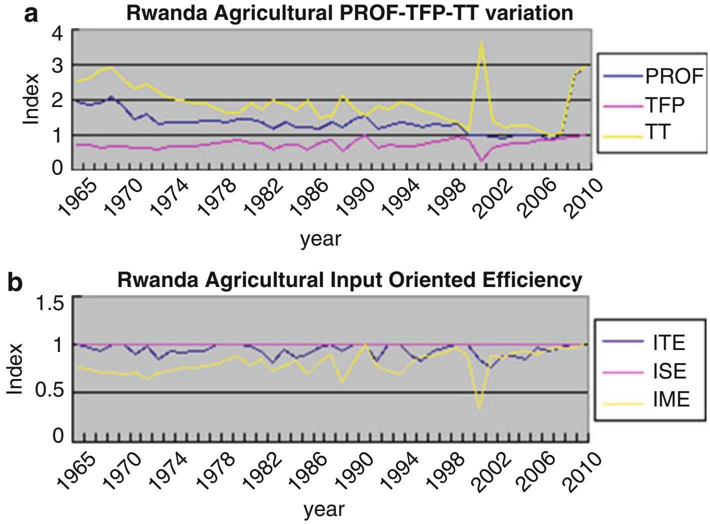

Fig. 8 (**a**) Rwanda agricultural productivity, profitability, and term-of-trade variation between 1965 and 2010. (**b**) Rwanda agricultural oriented inputs efficiency variations between 1965 and 2010 (Sources: author own composition based on FAO emission database)

change is much lower after. There is no significant change in scale efficiency. This is illustrated in Fig. 9b.

In summary, over the considered, period agricultural productivity is low across countries with relative improvement after the liberalization. However, in term of inputs used efficiency, there is no observed changed at scale level over the whole period. This explains that producer resource allocation does not change significantly, while production technical change has relatively changed over the years. This highlights on inefficiency of agricultural inputs such as labor fertilizer, water used in these countries, and their intensive agricultural production system. Therefore, inefficient fertilizer applied may contribute to increase in the sector emission, while climate change impact on water may increase water availability which in return will affect the sector productivity.

However, analysis of the result of the regression between country agricultural productivity and number of agricultural research staff, expenditure in agricultural R&D, government effectiveness, land, labor, and AFOLU emission reveals that agricultural emission and forest land net emission have similar significant impact on agricultural productivity as R&D, agricultural extension, government effectiveness, land, and labor, while the impact of land use on agricultural productivity is not significant. This is illustrated by list of Tables 5, 6, 7, and 8. Therefore, mitigation action in land use could be a possible option but will not have any gain or loss in this study's selected countries performance improvement.

It shows that total agricultural emission has considerably reduced country agricultural productivity respectively by 1.67 at 70 % in Ghana, by 0.04 at

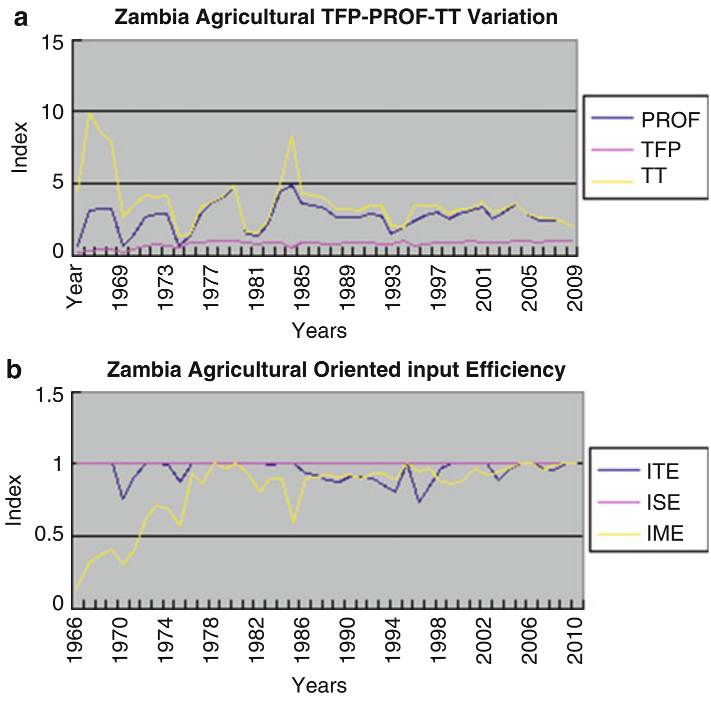

Fig. 9 (**a**) Zambia agricultural profitability, productivity, and term-of-trade variation between 1965 and 2010. (**b**) Zambia agricultural oriented inputs efficiency between 1965 and 2010 (Sources: Author own composition based on FAO emission database)

Table 5 Robust regression with standard error assessing Ghana agricultural TFP driving factor

TFP	Coefficient (robust)	Standard error	t	P > t	95 % Conf.	Interval
Agriex	−4.050169	1.025168	−3.95	0	−6.125514	−1.97482
R&D	0.3604969	0.2699032	1.34	0.19	−0.185893	0.906887
GOVEFF	0.6753189	1.478932	0.46	0.651	−2.318622	3.66926
Land	−0.8363213	0.266972	−3.13	0.003	−1.376778	0.2958
Labor	3.773906	1.021545	3.69	0.02	1.705897	5.841915
A	−1.672057	0.6883586	−2.43	0.02	−3.065566	−0.27854
Constant	−33.75379	10.51329	−3.21	0.003	−55.03685	−12.4707

Number of observation 45, F(6,38) = 16.85, Prob > F = 0, R-square = 0.7098, Root MSE = 0.24017

35 % in Zambia, and by 0.66 at 19 % in Rwanda. This means that emission from agriculture sector does contribute to decrease in Ghana, Zambia, and Rwanda agricultural production performance. However, in Kenya, it is found that the emission from agricultural sector contributes to improvement of the country agricultural productivity. This confirms the need of exploring the linkage

Table 6 Robust regression with standard error assessing Kenya agricultural TFP driving factor

TFP	Coefficient (robust)	Standard error	T	P > t	95 % Conf.	Interval
Agriex	−0.242240	0.367796	−0.66	0.514	−0.9868058	0.5023245
R&D	0.3246712	0.362694	0.9	0.376	−0.4095651	1.058907
GOVEFF	0.1349451	0.2387321	0.57	0.575	−0.3483428	0.6182329
Land	0.0686824	0.3998275	0.17	0.865	−0.740726	0.8780908
Labor	0.0741058	0.353813	0.21	0.835	−0.6421513	0.7903628
A	0.6603873	0.4720294	1.4	0.17	−0.2951861	1.615961
Constant	2.002648	6.287847	0.32	0.752	−10.72643	14.73173

Number of observation 45, F(6,38) = 16.85, Prob > F = 0, R-square = 0.1920, Root MSE = 0.24017

Table 7 Robust regression with standard error assessing Rwanda agricultural TFP driving factor

TFP	Coefficient (robust)	Standard error	T	P > t	95 % Conf.	Interval
R&D	0.4369153	1.753359	−0.25	0.805	−3.989559	3.115728
Agriex	1.3845	0.706660	1.96	0.058	−0.0473301	2.81633
GOVEFF	0.1145932	0.15654	0.73	0.469	−0.202605	0.431791
Land	0.0259382	0.022671	1.14	0.26	−0.019999	0.071875
Labor	−0.153022	0.278233	−0.55	0.586	−0.716776	0.410731
A	−0.004775	0.212172	−0.02	0.982	−0.434676	0.165598.1
FO	2.156108	0.71087.537	0.3	0.763	−0.1224759	0.165598.13
Constant	1.481708	0.4931127	0.3	0.765	−0.8509705	0.114731.2

Number of observation 45, F(6,38) = 16.85, Prob > F = 0, R-square = 0.197, Root MSE = 0.24017

Table 8 Robust regression with standard error assessing Zambia agricultural TFP driving factor

TFP	Coefficient (robust)	Standard error	T	P > t	95 % Conf.	Interval
R&D	−0.175120	0.2671969	−0.66	0.516	−0.7160325	0.3657911
Agriex	1.349458	0.579199	2.33	0.025	0.1769307	0.3657911
GOVEFF	0.9373663	0.8151916	1.15	−0.257	0.7129029	2.587635
Land	2.215054	0.8151916	2.23	0.032	0.2068688	4.22324
Labor	−0.512447	0.9919933	−0.93	0.358	−1.628473	0.6035787
A	−0.0664795	2,412,561	0.28	0.784	0.421918	0.5548769

Number of observation 45, F(6,38) = 16.85, Prob > F = 04, R-square = 0.35, Root MSE = 0.36

between agricultural productivity improvement and emission impact according to each country's statement. The main reason is the complexity of country's agricultural production system and their agroecological zones. The result of this study of course does not support emission increase in Kenya but highlights that emission reduction could improve the country's agricultural production performance, as can constitute constraints for a country like Kenya that will need to achieve national goals in this sector. The cost of any emission reduction strategies then needs to be evaluated.

Notwithstanding, forest land net emission/sink impact on agricultural productivity has been significant only in Rwanda. It has contributed to the improvement of the country's agricultural performance by 2.1 at 19 %. This supports the fact that forest land in Rwanda has high carbon sink potential and deforestation will obviously reduce that sink. This is also consistent with the result of Rose et al. (2012) on analysis of agricultural productivity and deforestation. He found that improvements in Latin America or Southeast Asian crop TFP (ceteris paribus) led to an increase in inaccessible and accessible forest loss and pasture land conversion to cropland.

Therefore, considering 2010 as baseline, any 1 % increase in agriculture emission will decrease agricultural productivity in Zambia by 0.04 %, in Rwanda by 0.66 %, and in Ghana by 1.67 %. This will contribute to a decrease in their respective performance and will require then more investments in order to mitigate emission from agriculture. This will cost respectively 46.40Cedis/t/ha (US$ 23.2) in Ghana, 49.25 ZMK (US$ 0.09) in Zambia, and 346 FR/t/ha(US $0.53) in Rwanda. While in Kenya any 1 % decrease in agriculture emission will cost 2062.5 Ksh/t/ha(US$23.5). Therefore, the opposite scenario means a gain in each country.

Similarly, any 1 % decrease in forest emission through afforestation/reforestation in Rwanda will contribute to improve the country's agricultural productivity by 2.15 %. This will contribute to save 152 Rwanda Franc/tone/ha(US$ 0.23).

In a related development, the CAADP goal of achieving 6 % of agricultural productivity toward 2015 will increase the country's annual mitigation potential in agricultural sector by respectively 3.75 % in Ghana, 100 % in Zambia, and 150 % in Rwanda. While in Kenya it will contribute to an increase of the country emission by 9 %. Moreover, in Rwanda it will create an additional 2.85 % increase for the country forestry land emission. This means that the policy will help to reduce the total agriculture emission in Ghana and yield 0.00019 Gg CO_2 eq., while in Zambia the agriculture will become carbon neutral.

Nonetheless, the policies will transform Rwanda from net total agricultural emission to yield agricultural sink country at −0.0000319 Gg CO_2 eq., while the country forestry sink potentiality will increase and yield −1.31 Gg CO_2 eq.

In contrast, the policies will increase the total agriculture emission in Kenya and will yield 0.0068 CO_2 eq.

Conclusion

Agricultural productivity is relatively low in sub-Saharan Africa. Despite several reforms, it is even below the world average. Indeed, most countries did integrate the sector economics liberalization into their economics market liberalization in 1990.

The agricultural productivity did increase relatively during the period of post-economic openness. The relatively low agricultural productivity during the post-market liberalization is also observed in this study's selected countries. Indeed, the goal of improving the sector productivity rises during this decade and becomes a priority in most government policies' agenda. This includes the Comprehensive Africa Agriculture Development Programme. The policy is expected to bring annual growth of 6 % of TFP. This leads to expansion and intensive agriculture practices in some countries. However, the debate created by recent study which identifies agricultural sector as main emission sources in Africa raises more interrogation between scholars and government on the trade-off between productivity improvement and mitigation action in agriculture sector. This study finds that mitigation action in agriculture sector could help to reduce emissions and improve the sector productivity. However, not all mitigation action will contribute to improvement of the agricultural sector performance improvement. Therefore, some mitigation will also contribute to deterioration or decline in country agricultural production performance. This is the finding in this study's sampling countries.

Mitigation action will increase agricultural productivity in Ghana, Zambia, and Rwanda, while it will decrease productivity in Kenya. The need of implementing appropriated mitigation action is therefore essential. Appropriated sustainable land management (SLM) practices taking into account the country's agroecological zone, appropriate technology, and farmer ability to adopt the technology coupled with available resources will be more suitable for improving the country's agricultural production performance. Moreover, SLM could be developed toward climate smart agriculture (CSA) concept.

Indeed, the effects of land use changes are not significant and do not contribute to any changes in the selected country's agricultural production performance. This emphasizes that mitigation action can be assessed only by analysis of the response of each country's agricultural production system.

Therefore, the debate on how African countries will respond to mitigation action commitment in agricultural sector will depend on the impact of emission in agriculture sector and how emission reduction could benefit the sector. This includes the cost of the implemented mitigation action.

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Multilevel Analysis and Comparison of Climate Change Policies in Argentina and Canada

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Abstract

Purpose – This chapter discusses and compares the climate change policies of Argentina and Canada at the international, national, and local level. Starting with a discussion of both Argentina and Canada's positions in the UNFCCC, the chapter then explains the positions and policies that have been implemented in the national and then local level of each country.

Methodology/approach – This chapter is an analysis and comparison of laws, policies, and practices through not only a discursive analysis of their official positive legal meaning but also through an analysis of their actual applied impact. A multilevel institutional analysis is utilized such that the climate change policies of Argentina and Canada are analyzed at the international, national, and local level.

Findings – At the international level, a discourse surrounds Argentina and Canada in terms of developing and developed country and global justice. At the national level, each country has different official laws and discourses surrounding climate change; however, at the regional level in both countries, many similarities exist in respect of climate change mitigation and adaptation in both positivistic legal meaning and actual applied reality. This chapter hypothesizes that a problematic gap exists between the climate change institutional framework and the "real" climate change being experienced by local people.

Practical implications – The similarities in the actual applied experience of climate change mitigation and adaptation in Argentina (a developing country) and Canada (a developed country) at the regional level, contrasted with the different characteristics at the national and international level, offer insights into the challenge of effective implementation of climate change mitigation and adaptation.

Originality/value – The multilevel institutional analysis and comparison of Argentina and Canada in respect of climate change mitigation and adaptation reveal significant structural governance challenges for the effective implementation of climate change mitigation and adaptation goals of the UNFCCC. Overcoming these challenges may facilitate implementation of climate change mitigation and adaptation goals.

Keywords

UNFCCC • Climate change mitigation • Climate change adaptation • Multilevel institutional analysis

Introduction

This chapter discusses and compares the climate change policies of Argentina and Canada using a multilevel institutional approach focusing on the international, national, and local level. The local level selected in Argentina is Mendoza; in Canada, the Prairie Provinces of Alberta and Saskatchewan have been selected. Argentina and Canada's positions in the UNFCCC are strikingly different, but many similarities exist at the local level. Both are water-scarce areas with significant irrigation and some similarities in institutional context at the local level surrounding climate change, although at the international level they are very different, one being a developed and the other a developing country. This chapter explains the positions and policies that have been implemented in the national and then local level of each country, assessing the policies' actual impact hypothesizing that there is a problematic gap between the climate change institutional framework and the "real" climate change local problem.

In the Canadian case, it is anticipated that climate change will result in increased water scarcity, more frequent extreme events (e.g., droughts, floods, storms), and changes or disturbances in climate regimes which will impact ecosystems with such events as forest fires; insect outbreaks (e.g., mountain pine beetle); vector-borne disease, such as West Nile virus; and the introduction of nonnative plants and animals. All of these impacts will place significant pressure on the environment as well as on human activities, such as farming, agriculture, forestry, development, and industry in the Prairie Provinces (Sauchyn and Kulshreshtha 2008).

Mendoza's regional productive model, based on Andean irrigated oasis agriculture, is seriously threatened in the context of most climate change scenarios. Global climate change projections indicate a probable decrease of snow in the mountains with a consequent decrease in the yearly streamflow (Boninsegna and Villalba 2006a, b). These climate factors could seriously increase the water deficit and compromise the oasis survival (Boninsegna and Montaña 2013). The Prairie Provinces are in central Canada. Mendoza Province is in the Central West region of Argentine, by Andean cordillera. The yearly precipitation is scarce (200 mm) and occurs during hot summers, frequently with hail. Additionally, the high levels of sun radiation have a direct impact on evapotranspiration and therefore on crops' water stress.

This chapter will demonstrate that the institutions that best address the "real" climate-related local problem of water scarcity are very far from the mitigation and adaptive practices that the climate change paradigm promotes. The practices of institutions with climate and agriculture mandates focus on an agricultural production model, not the climate change problem. These institutions are good information producers, but are not grasping the "real" climate change local problem of water scarcity.

Position of Argentina and Canada at the UNFCCC

The United Nations Framework Convention on Climate Change, the international treaty whereby parties cooperatively consider actions to limit average global temperature increases and resulting climate change, was ratified by Canada in 1992 and Argentina in 1994 (UNFCCC 2013). Kyoto was the significant legally binding agreement on emission reductions. Kyoto, however, did not provide for legal remedies and was therefore a rather toothless agreement (Pardy 2004). In Doha, Qatar, in 2012 the Kyoto Protocol was amended such that Annex I parties agreed to a second commitment period from January 1, 2013, to December 31, 2020 (UNFCCC 2013). Canada, an Annex I country, withdrew from the Kyoto Protocol providing notice in December 2012 and terminating its commitment in 2013 (United Nations 2012).

The communication filed by Canada in 2010 with the UNFCCC Secretariat stated that Canada expected to be 802 Mt above its Kyoto Protocol target of 2,792 Mt during the 2008–2012 period (Government of Canada 2010). The latest communication filed by Canada states that Canada emitted 702 Mt of GHGs that year, about 19 % above its 1990 total of 591 Mt, excluding the land-use change and forestry (LULUCF) sector. Currently the energy sector is responsible for the majority of emission (81 % consisting of stationary combustion, transport and fugitive emission sources) and the agricultural sector responsible for only 8 % of emission. Some reduction has occurred since 2008 (Government of Canada 2013). These reductions are touted to be as a result of regulation within the transportation and energy sector, as well as reduced manufacturing sector emission. Unstated is the fact these reductions could be as a result of the global recession that has occurred since 2008.

When in December of 2011, Canada withdrew from the Kyoto Protocol, the conservatives blamed the liberal government for having made an error committing to the protocol. Prime Minister Stephen Harper has set a target of reducing annual emissions to 17 % below 2005 levels by 2020. This is a much lower threshold to meet than the initial Kyoto Protocol target of cutting below 1990 emissions levels (CBC 2011; De Souza 2012). Publicly the Prime Minister had rejected carbon pricing or a carbon tax (supporting regulating each sector instead) and closed the National Round Table on the Environment and the Economy because the research group promoted carbon taxing (Scoffield and Ditchburn 2012). However, in Privy Council documents obtained under access to information legislation, Canada stated it supported the development of new market-based mechanisms expanding the scale and scope of carbon markets (De Souza 2013). It would appear that currently the Canadian government's position on climate mitigation is somewhat confusing. At this time, no legislated carbon reduction measures are in place in Canada.

Argentina ratified the UNFCCC in 1994 and the Kyoto Protocol in 2001. Argentina, a non-Annex 1 country, has submitted two national communications: the first one in 1997 – revisited in 1999 – and the second one in 2006. The third communication is in the process of being prepared. During this period, Argentina has adopted several mitigation norms and regulations, specifically to reduce emissions. Argentina's position in the context of climate change commitments has changed since the signature of the agreement, moving from a proactive innovative position to a low-profile one. In 1999, at COP 15, Argentina announced an emission reduction target linked to its GDP (SAyDS 1999). At that moment, this was an innovative event because it was the first time that a developing country had agreed to meet a voluntary quantified GHG limitation target. The proposal meant that Argentina was not locked into a fixed emission level as had been the case of the commitments adopted by developed countries under the Kyoto Protocol. Rather, Argentina would be allowed emission increases according to economic development (Conte Grand

and D'Elía 2011, p. 2). But this active role and innovative goal lasted a short while. Actually, by the time this target was presented, a new government had already been elected in Argentina, and its new authorities had announced that they would not agree with this commitment. Following governments have maintained the same position (Conte Grand and D'Elia 2011).

Argentina's current position is the "common but different responsibilities" principle (Chojo 2011). (This principle indicates that developed countries with greater resources (the *historically responsible countries*) must fund projects outside its borders in developing countries.) As was defined by the now ex-president Kirchner, Argentina is an environmental creditor, and it will charge developed countries in sustainable growth. Nowadays Argentina generates 6 % of the global emissions (WRI 2011). Overall emissions increased by 4.1 % from 1997 to 2000. As has been evidenced in the 1990–2000 inventories, GHG emissions originate mainly in the energy sector (including transportation) and 44 % in the agriculture and livestock production sector (Di Paola and Rivera 2012, p. 14) The weight of agriculture emissions (half of total national emissions) is very important. This is why taking only into account the energy sector emissions may lead to erroneous interpretations of the local contribution to climate change (Honty 2011, p. 55). Actually, some reports (not authored by the government) assessing scenarios emissions by sectors claim that the agricultural sector is not the second but the first source (CEADS 2012). In addition, agriculture emissions are also alarming in another sense. Argentina's profile as a highly agriculture country, where grain and agricultural products export are the main national revenue, makes it very vulnerable to climate variability. Extreme events could seriously affect the prices of commodities. Emission scenarios emphasize the importance of making changes, if Argentina wants to improve its resilience.

The national positions of Argentina and Canada are very different. Canada appears committed in principle to the reduction of GHG emissions and its pledges at Copenhagen; however, it has pulled out of any legally binding pledges of emission reductions. From a legal positivist stance, it is not required to take any future action. Argentina on the other hand has claimed entitlement to increasing its GHG emissions through the principle of common but differentiated responsibility. Each country has situated itself within the discourse that exists at the international level surrounding developing and developed country and global justice. The situation at the national and regional levels of each country is, in contrast to this, quite similar.

Climate Change Institutions at the National, Regional, and Local Level in Argentina and Canada

The institutions involved in climate change at the national level, and then the regional/local level, will be discussed starting with Canada and then Argentina. Thereafter, the climate change policies at the national, regional, and local level in Argentina and Canada will be outlined. An analysis and comparison of Canada and Argentina, their institutions, mandates, and practices will follow.

Climate Change at the National Level in Canada

Canada is a federal country, and accordingly different functions are assigned at the federal and provincial level. In Canada, at the federal level of government, two departments have been tasked with key lead climate change responsibilities: Environment Canada has a specific role in relation to mitigation of greenhouse gases, while Natural Resources Canada has specific responsibilities in relation to adaptation to a changing climate. These are the two most important departments, although other federal government agencies and departments also have roles in relation to climate change such as Health Canada with its role in safe drinking water and Parks Canada with its mandate for water resource management and protection within national parks.

Environment Canada has a mandate to preserve and enhance the quality of the natural environment, conserve and protect Canada's water resources, forecast weather and environmental change, enforce regulations relating to trans-boundary waters (international and interprovincial), and coordinate environmental policies and programs for the federal government. Because of Environment Canada's mandate, changing weather and, hence, climate change itself are central to aspects of its mandate. In addition to its long-standing environmental protection mandate, Environment Canada is responsible for overseeing the federal government's plan on the reduction of greenhouse gas emissions and the regulatory framework supporting this plan. The central regulatory tool in the reduction of greenhouse gas emissions established by the federal government is the *Clean Air Act* (Bill C-30 tabled in 2006 as "An Act to amend the Canadian Environmental Protection Act, 1999" in the First Session of the 39th Parliament) which will be the responsibility of Environment Canada. However, this act still has not been proclaimed and become Canadian law.

Canada's latest communication to the UNFCC states that Canada takes a sector-by-sector approach to mitigation and cites regulatory changes in the transport and energy sector (Government of Canada 2013). One group, the Large Final Emitters Group, was established in 2002 as part of Natural Resources Canada, but with the release of *Project Green: Moving Forward on Climate Change* in 2005 (Environment Canada 2009), the group was transferred to Environment Canada given the government's intent to regulate Large Final Emitters under the *Canadian Environmental Protection Act, 1999*, S.C. 1999, c. 33. This group, made up of staff of Environment Canada, is responsible for working with key industry sectors to reduce annual greenhouse gas emissions. Through its discussions with industry, provinces and territories, and other stakeholders, the Large Final Emitters Group was tasked with designing policies and measures that are effective in encouraging reductions and are administratively efficient and clear while still maintaining the competitiveness of Canadian industry. In 2004 Environment Canada mandated that large facilities report greenhouse gas emissions through the Facility Greenhouse Gas Emissions Reporting Program (Canada 2012a). The 2001 report shows that while large electrical utilities in Canada have reduced greenhouse gas emissions in Canada by 32,278 kt, non-conventional oil extraction have increased this number by 20,706 kt from 2005 to 2011 (Environment Canada 2013).

Natural Resources Canada promotes the responsible use of natural resources (mining/materials, energy, forests, hazards, explosives, the north, earth sciences, and the environment) for the protection of human health, the environment and the landmass, and other research related to forestry, mining, and energy sectors. Natural Resources Canada leads the development of the Northern Gateway Pipeline Project, a contentious development to transport energy across Canada's north for export. At the same time, Natural Resources Canada's Environment section leads impacts and adaptation to climate change and conducts climate change research.

Although other departments may have minor roles in climate change, the next most significant federal department involved in climate change, Agriculture and Agri-Food Canada (AAFC), has undergone significant cuts in the recent past reducing its climate change mandate. The Prairie Farm Rehabilitation Administration (PFRA) was created as a special agency in 1935 in response to severe climate impacts on the Prairies caused by the multiyear droughts of the 1920s and 1930s. Its mandate related to improving the security of prairie land and water resources to achieve greater economic security of agriculture in the semiarid prairie region; its role recently evolved to include national agri-environmental activities related to promoting farm practices that afford a competitive profitable agricultural sector with improved protection of the environment from potential agricultural contamination risks. PFRA was incorporated into Agri-Food Canada in 2009, and then its staff mostly phased out through retirement in 2012 onwards (Hurlbert et al. 2010).

The Provincial Level in the Prairie Provinces

The provincial governments of the three Prairie Provinces have similar challenges within the bureaucratic structure in responding to climate change because of the breadth and depth of the challenge and the preexisting government structure of institutions created prior to today's focus on climate change and water. Each province's response to climate change has been somewhat different in both form and substance. Generally, one particular provincial department is tasked with climate change, and a few others have supporting mandates or programs. One similarity between the provinces is that municipalities have a very localized role in relation to providing drinking water to residents, responding to floods and emergencies, and land-use planning decisions within their borders.

In Alberta, Alberta Environment is tasked with addressing climate change. After establishing its 2002 climate change plan and after a series of public meetings, Alberta renewed its climate change plan early in 2008 (Alberta Environment 2008). Alberta Environment is also tasked with both the protection and wise use of the environment and natural resources. Most activities affecting the environment must be reviewed through environmental assessment by Alberta Environment. Alberta Environment also carries the bulk of the responsibilities relating to both water and the environment, which includes surface and groundwater allocation, flow regulation, water supply and flood forecasting, pollution control, regulation of municipal potable water systems, and developing watershed management plans in conjunction with local groups. Alberta Environment also establishes and enforces drinking water and wastewater objectives and legislation.

In Saskatchewan, the ministry of the environment has been central in developing a climate change strategy. This ministry protects and manages Saskatchewan's natural resources, leads environmental water quality monitoring and enforces environmental protection guidelines, sets water quality regulations and objectives (including those for drinking water and waste water), and retains legislative responsibility for enforcing municipal drinking water regulations. Unlike Alberta, which manages both climate and water resources under the environment department, Saskatchewan manages its water resources by a separate Crown corporation, the Saskatchewan Water Security Agency. The Saskatchewan Watershed Authority (the Saskatchewan Water Security Agency's predecessor) was created to manage water in a holistic fashion aimed at protecting water source; the agency was established in 2002 as a direct response to the North Battleford drinking water disease outbreak in 2001. Saskatchewan Watershed Authority is responsible for protecting source water by promoting stewardship, water management, and water allocations and diversions and developing watershed and source water protection plans in partnership with watershed groups. Other departments also play a key role in responding to climate change, including the Ministry of Agriculture in respect of farming, improving farming practice, enforcing the Agricultural Operations Act, promoting environmental farm planning, and encouraging the adoption of agricultural beneficial management practices (BMPs) to protect water resources and the environment.

Climate Change at the National Level in Argentina

Argentina, as Canada, is a federal country and its national constitution (1994) confers provincial states primary ownership (*dominio originario*) of natural resources (including water and land). In relation to **adaptive practices**, the federal government's ability is limited as it does not have any jurisdiction in relation to natural resources. Argentina does not have a specific national **law or legislation on climate change** (in fact, the minimum environmental protection Presupposition law does not contemplate climate change or adaptation practices). General Environment Law N. 25.675 is the most general related law and stresses the necessity of interjurisdictional coordination in terms of environment ordering. It is a thoroughly promising law as it establishes interesting guidelines that help decrease national state development which would be at the expense of that of provincial states (thereby retarding their development) (Salerno 2009, p. 310). However, its resource limitations restrain an adequate enforcement of the law (Cetrángolo et al. 2004).

Also at the federal level is the Secretary of Environment and Sustainable Development (SAyDS). This entity is the authority for the enforcement of the law 24295 by which Argentina ratified the UNFCCC (Presidential Decree 2213 of year 2002). Within this Secretary, the Unit of Climate Change (UCC) was created to advise SAyDS Director on Law 24295 application and UNFCCC implementation. Many other governmental areas have responsibilities on climate change issues. One of these is the Environmental Federal Council (COFEMA) which brings together all provincial environment departments with national government representatives. Within this council, there is a special group on climate change. The expectations on this council were many because it was supposed to be an organ exclusively created to integrate provincial and national visions. However, so far it has shown major limitations of resources (technical and financial) and an unbalanced political weight. So as yet, it has not achieved a genuine incorporation of provincial visions within the national environmental strategy.

The last institution is the Climate Change Government Committee where government organisms, important public institutions, and COFEMA representatives meet. All these institutions lead by CCO develop the Climate Change National Strategy (CCNS), the major national climate change policy instrument.

The Provincial Level in Mendoza

At the provincial level, in Mendoza two institutions are supposed to be related to climate concerns – at least they have the "climate" word in their name. The Climate Change Agency was created in 2007 as a coordination arena between public and production sectors, science institutions, and NGOs. According to its official site, its goal is "to promote programs and environmental, social and economic projects including provincial, national and international public and private sectors...; to prevent actions that may cause ecological damage or affect province natural resources quality and preservation... and to recommend mitigation practices and adaptation strategies to minimize climate change consequences in Mendoza" (Agencia Mendocina de Cambio Climático (n.d.)). An intention so wide, intangible, and nonspecific has left this institution achieving little. But the real weakness of this institution is that it does not handle its own funds. Instead, it must rely on the meager amounts derived from federal programs which in turn are received from international organizations. This situation leaves this agency as *just as a lot of good intentions*. The second climate provincial institution is the Agriculture and Climate Contingency Directorate. This is the provincial *agri-climate* referent. Its goal is to assess extreme climate events, but it is mainly concerned with supporting farmers avoiding agricultural damages, specifically hail and frost. The Climate Change Agency depends on the Land, Environment, and Natural Resources Ministry and is oriented toward sustainability and resource conservation; the Agriculture and Climate Contingency Directorate depends on the agri-industry and technology ministry with a completely different orientation toward agricultural development.

One last institution in Mendoza is definitely dominant in dealing with climate and water resources: the General Irrigation Department (DGI). Although formally it does not have a climate mandate, it does in practice given that the main local global change problem is drought. As DGI is the most important water government institution – in a land where irrigated agriculture is the only possible – it turns into the most significant institution for coping with "real" global change problems, even more than the other two mentioned. DGI is a strong institution that since 1884 has been modeling the wine regional agriculture production model. This strength comes from a development model established in 1884 (the year in which the current water law in the province was enacted): water coming down the Andes is stored, distributed, and systematized in agricultural irrigation systems and finishes as crops or virtual water for export. Water management is a key support for this model which is still valid today. In 1884 it was designed by a planning elite with enough political, social, and economic power to influence the productive destinations of the region. This has not changed: today DGI meets the interest of the most wealthy and powerful regional producers and remains far from adaptive also avoiding mitigation practices that climate problems demand. Currently Mendoza's provincial constitution states guidelines for water, but environmental policy is lacking here.

Finally, at the bottom level, municipalities also have specific domains related directly to environment, but these are mainly rhetorical offices. Instead, these are the municipalities' production offices which are, "in the real world," the closest government institutions to small farmers. But at the same time they are the least economically empowered institutions. They can hardly provide material support but advice small farmers how they should proceed claiming other levels.

Climate Change Policies at the National, Regional, and Local Level in Argentina and Canada

In Canada, provincial and federal ministries appear to overlap or duplicate climate and water mandates and services. Because climate was not contemplated when Canada mapped out jurisdictional matters between the federal and provincial governments in its constitution of 1867, it spans both levels of government. Similarly, the jurisdictions of natural resource management are shared by mutual agreement and often by joint programming and funding between the national and provincial governments in Canada. The potential duplication is resolved in practice in two ways. Firstly, matters which are within federal jurisdiction such as First Nation lands, international and interprovincial waters, and interprovincial undertakings are governed by the federal government departments and legislation; matters within provincial control, such as provincial lands and natural resources (including water management), are governed by the provincial legislation and policy of the provincial government departments. Secondly, in the event that it is not clear whether a particular issue or activity falls under provincial or federal government jurisdiction, there are many federal and provincial agreements resolving these issues, which generally provide that the strictest legislation shall apply. For example, under administrative or equivalency agreements with many provinces, federal environment legislation is held in abeyance providing provincial legislation is equivalent to, or more stringent than, that expressed in federal acts. Agriculture, water, and environmental issues are commonly shared jurisdictional matters between the federal and provincial governments. The Prairie Provinces have had specific policies surrounding climate change and adaptation for the past several years.

The Canadian government, led by Prime Minister Stephen Harper, has been accused of "muzzling" its scientists by not allowing them to speak to journalists without preapproval, which is often denied (Ghosh 2012; Burgmann 2012). Having pulled out of the Kyoto Protocol and having officially rejected a carbon tax, the federal government led by Prime Minister Stephen Harper introduced the *Clean Air Act* (Bill C-30 tabled in 2006 as "An Act to amend the Canadian Environmental Protection Act, 1999" in the First Session of the 39th Parliament). This draft bill was amended in 2007, but has not yet been passed into law. Instead, $345 million of funding was allocated to promoting the use of biodiesel and ethanol and $300 million to helping homeowners become more energy efficient (CTV News 2006, 2007). In addition to other grants to cities and provinces for various initiatives including transit initiatives and climate impact research in the Arctic, in 2009 billions of dollars were allocated to clean energy research and development and demonstration projects such as carbon capture and storage and energy retrofit programs, aimed at improving the environment as well as employment opportunities (Canada 2009). Canada has invested $236 million since 2006 in climate adaptation initiatives (Government of Canada 2013).

Saskatchewan's previous New Democratic Party Government issued an Energy and Climate Change Plan in 2007 which was a cross-governmental vision in response to climate change and the development of a province-wide climate change adaptation strategy which included working with research organizations and supporting critical local research on climate change and adaptation (Government of Saskatchewan 2007). These goals have been reiterated in the 25-Year Saskatchewan Water Security Plan (2012). Several watershed groups have developed drought plans as outlined above. Currently, climate legislation relating to mitigation remains on the legislative agenda but is yet to be proclaimed.

In Alberta legislation has been in existence since the Climate Change and Emissions Management Act (2003), a precursor for Alberta's Climate Change Strategy (Alberta Environment 2008). In addition to establishing a carbon offset market and providing consumer rebates in relation to energy efficient products, two programs were also introduced, a greenhouse gas reporting program and a greenhouse gas reduction program. These relate to the establishment of a greenhouse gas limit. In 2003 Alberta also created a "Water for Life Strategy" focusing on issues of quantity, quality, and conservation of water, all important issues in preparation for and during drought. The strategy initiated three important activities: (1) planning for future management of water via the provincial climate Change Adaptation Strategy, (2) development of land-use frameworks, and (3) watershed planning through local watershed groups. Alberta has policies in place to mitigate climate change. Alberta has passed legislation requiring large emitters to reduce their emissions by 12 % using an average of 2003 as a baseline. These requirements apply to emitters making up 70 % of Alberta's emissions.

In Argentina the Climate Change National Strategy (CCNS) is the most important climate policy instrument. Although it is not finished yet, since its origin in

2009, the strategy set up under two axes (mitigation and adaptation) which include a considerable number of action guidelines that include commitment and participation of different sectors, institutions and important actors, programs, projects, and also specific indicators to assess or measure the changes (Nazareno 2013). According to what has been reported in its Second National Communication, Argentina has implemented some measures to comply with the UNFCCC, especially mitigation practices to cope with GHG reduction. These include a carbon fund to encourage projects under the UNFCCC's Clean Development Mechanism (SAyDS 2008), a National Program for Rational Use of Energy and Energy Efficiency (United Nations 2011), a national program encouraging the use of bioethanol and biodiesel (ibid.), a law for the sustainable management of forests, and an urban solid waste management plan supported by a loan from the World Bank for constructing sanitary landfills and landfill gas capture (ibid.). The SAyDS, in agreement with the provinces and with the funding of the World Bank, has developed since the year 2005 an Urban Solid Wastes National Strategy. Given that around 60 % of the disposal of urban solid wastes is still in open air dumps, the central objective of this strategy is the protection of the health of the population by the replacement of these dumps with controlled landfills. Likewise, the subsequent capture and elimination of the methane are also contemplated in this strategy (second communication).

Lastly, the *glaciers preservation,* Law N. 32.016, which has been recently created dictates minimum budgets for core presuppositions to protect nationally glacial water sources. Adaptation measures at the national level are much more limited than mitigation practices and include actions to reduce risk disasters in the land-use planning process and the agricultural sector.

At the provincial level, the Climate Change Agency defines as a priority energy and water efficiency, but their practices are limited to audits, diagnosis, and awareness of the population. Occasionally these activities articulate with activities in the municipalities but always limited within the framework of education campaigns. The Agriculture and Climate Contingency Directorate, as stated above, orients its policy toward damage prevention and mitigation, managing support and providing advice to farmers affected by frost and hail. DGI water policy is the most related to extreme drought events associated with GC in the region. Among the most important measures, Mendoza's DGI stated in 2014, for fourth consecutive year, water emergency. This statement is put into effect by decree of the governor, and it is a portfolio of measures to be implemented after the finding of a severe decline in river flows. While it is a big scope policy which it is supposed to reduce water availability for all uses, it affects mainly irrigation. The effect on livelihoods of farmers using irrigation water is different, as not all producers depend in the same way from water coming "down the river and channels." This large number of institutions formally designed to address the global change problem and their policies overlapped each other in their functions, which creates confusion among producers. More importantly, this situation creates few opportunities to be sensitive to the needs of producers affected by the effects global change.

Analysis and Discussion

The comparison of Canada and Argentina has been organized into three themes: the dominance of a model of production, institutional fragmentation, and institutional silos. In respect of institutional silos, the most problematic features of this are climate, water, and territory. Each feature will be discussed in turn.

The Dominance of a Model of Production

Argentina is an agricultural exporter and here lies its main income source. Therefore, it is highly vulnerable to climate variability and extreme events, as these can severely affect domestic production and the price of commodities worldwide. However, the long-term goals proposed in the CCNS are framed in the same production, reproduction, and consumption model that makes Argentina vulnerable (Llanos 2014). The national strategy planned to address global change focuses on how to adapt the current model of production to new climate conditions. The CCNS does not set specific rules to limit the expansion of the agricultural frontier and thereby to limit deforestation and soil degradation. This will result in the displacement of small farmers and original people living on the existing agricultural lands. Further, the strategy does not promote agri-ecological practices or introduce regulations to native seed conservation. Neither the global change nor climate change plans offer a strategy for the improvement of small and medium producers (Llanos 2014). By this, the government does not define clear measures that improve Argentina or reduce its vulnerable condition. Although a radical change of the agricultural model isn't anticipated, there is no clue of any robust mechanisms or alternative agricultural model that could take Argentina into a sustainable long-term adaptation process. Also considering that half of the total national emissions comes from agriculture sector, the current agriculture model reproduction included in the CCNS does not show a very promising picture for the country.

The continuity of the dominant agricultural model underlying Argentina's national position is also reflected at the provincial level. Although the wine production of Mendoza is not within the main exporting commodities of Argentina, the agency that administers the water (for irrigation) reproduces the poorly sustainable extractive production model through an unequal water allocation and discount system. Intuitively, opportunity to increase the export of this product is being foregone.

Canada too has a dominant model of production, albeit slightly different than the Argentinean agricultural model. In Canada, in the study region of the Prairie Provinces and post 2008 recession, the dominant model is that of energy exporter. Canada is the sixth largest energy producer in the world, after Russia, China, Iran, the United States, and Saudi Arabia (International Energy Agency 2013). This energy production predominantly occurs in the study region. The current national Canadian government and governments of Alberta and Saskatchewan are expending considerable effort in maintaining the energy industry attempting to build several pipelines to take the crude oil and tar sand oil out of the northern area of the province to refineries and customers around the world. This production model also exists within the agricultural sector in Canada where focus is on exports and increasing food production. Any adaptation measures focus on the adaptation of farming practices to meet a changing climate with very little, but occasional, consideration for or focus on an alternative model of agricultural production (See Magnon and Sommerville 2012).

This dominant production model especially that of energy production could be a cause for the skepticism to climate change among local producers, albeit change of this attitude was noted (as reported in Hurlbert 2011). A struggle is ongoing in the Canadian media in relation to climate change between deniers and science (Arnott 2013). The government agenda appears to support climate change deniers. Funding cuts to scientific research (CAUT 2013) and massive cuts to federally employed scientists have occurred and will impact the northern Prairie Provinces and its oil sands in a unique way. One specific example is the loss of 11 regional libraries of aquatic research and the disposal of a environmental study in relation to building an oil pipeline in the 1960s and 1970s (Galloway 2014). This research would have acted as a baseline for current proposed pipelines in the same area.

Institutional Fragmentation

The global change institutional framework in Argentina shows a multilevel network of global change – related institutions. But this complexity does not translate into better support to local actors who are affected by the events of global environmental change in different sites of the country. The continuity from national to provincial levels is a fragmented framework that becomes evident at the regional level (the province and municipal levels) and has a greater consequence on everyday life of regional production and its actors. DGI is the local institution that should best address the "real" global change local problem, although as it was already mentioned it is very far from mitigation and adaptive practice. DGI focus on an *agricultural production model* that does not consider the global change problem. At the same time, provincial climate institutions' practices do not grasp the "real" climate change local problem (drought and water scarcity). Due mostly to lack of funds, they are just good information producers. A problematic gap exists between the global change institutional framework and the "real" global change Mendoza regional problem: drought and water scarcity. Each institution meets or deals with different actors. One (province institutions governing water) oriented toward large (powerful) actors and the other (climate institutions governing *emergencies and municip*alities) to small (disempowered) producers.

Argentina's institutional features have an impact on local farmers and in their capacity to overcome climate problems. A study of local producer's perceptions on state institutions confirms the hypothesis about the gap and the lack of capacity to cope with and reduce the impacts of climate change events on local actors (Mussetta and Ivars, Interviews, Mendoza, September 2012).

This fragmentation creates a situation of uncertainty within actors and gives them a negative opinion of state institutions. This perception is general, but it changes within different actor profiles. Small producers have the firm conviction that they obtain "nothing" from the state. They evaluate it as a single homogeneous entity, and they do not distinguish between local, provincial, or national authorities or type of institution (if they are talking about tax collection agencies, research organizations, or others). The exception to this generality is the municipality. This is the closest state arm to small farmers, and accordingly, these are the institutions approached by farmers for immediate assistance, especially in extreme climate event situations. However, producers do not receive as much as they claim because municipalities do not have very limited resources or competences to solve the problems. Instead, local municipalities work as mediators between small farmers and other government levels.

From a different standpoint, larger producers understand and clearly differentiate the various state levels, and they have a much more complete knowledge of the complexity of the state bureaucracy in its various offices and functions. This knowledge allows them to access privileged information provided by the state and therefore be in a better position to access economic benefits (tax breaks, direct subsidies, state grants). Further, these actors distinguish "political" from "technical" agencies which allows them to make informed decisions on issues such as water supply, efficiency, and financing (ibid.).

In Canada, a multitude of water organizations and climate institutions exist at the federal, provincial, and municipal level which make interagency coordination an issue. Government officials are often confused themselves about mandates and roles let alone the public and agricultural producers. This has resulted in often frustration by agricultural producers in having to deal with a large number of agencies in relation to a specific problem (Hurlbert and Diaz 2013; Bakker and Cook 2011). There is not a national water strategy, therefore no effective Canadian water vision with clear priorities and a comprehensive policy approach and no comprehensive climate change and adaptation plan (Hurlbert et al. 2010). In Alberta, this has constrained the development of more agri-industry and further irrigation systems.

Clear inequity also exists in Canada in respect of adaptive capacity. First Nation communities are the most vulnerable, partly because of a history of colonialism that characterizes the integration of indigenous people in Canada (Magzul and Rojas 2006). The Canadian government agencies and their incentives and adaptation mechanisms have aimed at improving the competitiveness of the sector in global markets and thus fostered larger-scale production, larger farms, and larger equipment. Fewer producers are producing more crops. A relatively small group of large farmers has replaced many small producers (Hurlbert and Diaz 2013).

Institutional Silos

Another significant feature of the framework fragmentation is that climate and water (as well as territory, since local governments are responsible for land use) are separated and managed by different institutions as if they were three separate dimensions. **Climate** is institutionally managed by provincial agencies that are almost exclusively rhetorical and whose policies do not have any specific scope for adaptation to global change. **Water**, the main natural resource to address the climate change in dry lands such as Mendoza, is administered by an institution with a long-standing history which has all the resources to decide what, who, and how to target, not only the management of the natural resource, but the entire provincial production system. Finally **territory** is formally the responsibility of municipalities. If the attention of climate change problems **requires** a comprehensive approach, the design and institutional practice of what should be understood as the same interconnected problem is empirically separated and fragmented.

A similar situation exists in Canada. Climate is the jurisdictional responsibility of both the national government and the provincial governments. Only paltry amounts have been spent on addressing adaptation to global change. Water is a matter of provincial jurisdiction and managed in very different and disparate ways by the provinces. However, in reality a patchwork exists as pockets of federal jurisdiction are situated in interprovincial and international water, federal lands, and First Nation lands. Territory is situated at the municipal and provincial level with an interesting separation between land-use planning and water planning making integrated watershed management a stretch goal. The most problematic feature of this situation in both Argentina and Canada is the consequences on actors' adaptive capacities. The following pages, reflecting local producer perceptions, will set out this idea.

Climate: In the Argentinean case, climate effects assistance mechanisms (that the Provincial Climate Contingency manages) are designed for the larger producers, not for small ones. This is because this office sets so many restrictions (such as regulations, guarantees, or financial solvency) that small farmers are unlikely able to access benefits. Therefore, not only must producers cope with the significant problems associated with lack of water, but they also have to manage to overcome hail and frost damage. Supportive mechanisms are mostly only affordable by wealthier farmers. The Climate Contingency office in the end becomes barely helpful because it appears far from the small actors and has little influence on their likelihoods. On those occasions when small producers get some kind of aid, it is never enough to recover from damages. In addition to this situation, these groups of producers are also affected by other non-climate processes such the low crops prices in the general price structure. For small producers, it represents more a state-constraints source than a supportive office for contingency.

Similarly in Canada, large producers are the biggest recipients of national and provincial assistance. As an example, small farmers often find crop insurance unaffordable, and complaints have historically been more common in Saskatchewan than in Alberta (RCAD 2012; Warren and Diaz 2012). Alberta has more consistently provided financial resources to maintain attractive premium rates in the wake of major drought events. Frustration in Saskatchewan stemmed from the effects of severe drought in the late 1980s and 2001–2002 on the finances of the program when payouts overtook the value of farmer premiums and government contribution levels; the Saskatchewan program fell into deficit. In response, premiums were raised to levels that farmers found exorbitant, and payout levels were reduced during the 1990s and early 2000s. A new government elected in 2007 addressed farmer concerns by injecting the cash required to make premiums and payouts more attractive. Since 2007 farmer participation in crop insurance in Saskatchewan has increased significantly.

Paradoxically, in both Argentina and Canada, the state discourses, small producers emerge as the main object of protection. Among the major producers, and to a lesser extent among medium-sized producers, who are able to access those benefits, negative perceptions of state are not associated with lack of help for climate contingencies events but about the constraints of economic policies at the national level. In short, crop insurance in Canada and Argentina is not the same for all: not because climate contingency is not a general event, but because some are better prepared to avoid or overcome these effects (because in turn they can reach state-offered climate protection). Others are not, and this makes them more vulnerable.

Water: Water scarcity is a general problem, and all actors recognize it. In Argentina, the unequal treatment is seen both in superficial and underground water distribution. In the former, only those with water rights take part in the decision making processes. In the second, underground water pumping is not an actual option for everyone because of its high pumping cost. On the other hand, pumping permissions are not always within the legal framework. They are managed by DGI in a centralized and discretionary manner, in favor of powerful actors. Underground water is really significant as it is what makes the difference during scarcity and restricted irrigation. Fragmentation and differentiated traits depicted previously are confirmed by actors, especially the disadvantaged (small producers located in middle and low areas of the basin) far from the big water storage at the top of the basin (Montana and Boninsegna (forthcoming)). Producers recognize that it is the provincial irrigation institution (DGI) which would have the power and ability to solve this problem. But they also recognize that they cannot reach this institution, just the same as with the climate agency, although with some differences. Here, the restrictions identified by the producers are not exclusively objective (regulations, taxes impositions). Rather, the problem with DGI is associated with a nontransparent policy making style that for many years has been supporting wealthier wine producers. Small producers explain that in the middle part of the basin, the DGI allows large water splurges and nonlegal water appropriations, while in distal areas there are serious water shortages. Both situations are attributed to the poor organization of the DGI (*ibid.*).

Perceptions are different from the large producers' standpoint, especially situated at the beginning of the basin. This group suffers from water shortage problems, but when water coming down the channels is not enough – a regular occurrence – they use groundwater. So, their complaints are about restrictions on obtaining groundwater licenses during strong water crisis periods. However, they recognize DGI's effort in organizing a water supply system. This difference can be explained because large producers are located upstream and small producers instead are located at the most distal part of the basin. As big water reservoirs are at the origin of the basin, the impacts of a water crisis are notably different in each place. DGI emergency policies during water crisis periods do not ensure an equalitarian water distribution.

In the study area in Canada, only in Alberta is water fully allocated such that no further water allocations can be made. As a result, Alberta has pioneered a water system which operates both on water license allocation from the province as well as allows these interests to be traded separately from the land. Albeit this process has only occurred a handful of times, it is believed by some Albertans in the study area to have been facilitative in meeting challenges in the last significant drought event of 2001 and 2002. The ability to transfer water interests separate from land was cited as a reason why irrigators in the South Saskatchewan River Basin were able to trade water interests in exchange for compensation allowing some producers with adequate capital to grow a crop, while others received compensation. A very robust system of water monitoring and enforcement in this region exists which would have enforced a first in time first in right system allocating the scarce water to a handful of the oldest water licensees. Instead, government officials, irrigators, and others quickly negotiated a compromise allowing municipal water use and the arrangement previously referred to. In accordance with an interprovincial water sharing arrangement, water was delivered downstream to Saskatchewan at this time where water is not yet fully allocated and problems such as these are only starting to arise.

Territory: According to a provincial Territory Ordering Law (8051, year 2009) of Mendoza which establishes policy and guidelines for municipalities and provincial coordinated territory planning, the DGI is supposed to dictate where it would be possible or desirable to expand agricultural area. However, this expansion does not occur, rather the opposite, an encroachment on agricultural land. It is the municipality which grants land-use permissions, and as a result, urban encroachment regularly occurs. Some protection does occur for medium and small producers in the middle and lower areas of the basin in relation to industries such as that of small brick manufacturing expansion. As long as the industry is not too powerful, some protection is attained. An opposite situation is the case of businesses whose powerful real estate interests progress over the best land in the foothills, in the upland areas of the basin. Powerful groups lobby on urban land use and usually determine or influence water allocation and land-use changes to the detriment of those in the middle and lower areas of the basin.

In the Canadian province of Alberta where water is fully allocated, several plans have been drafted. Alberta's Water Act integrates water planning with a consultative policy first created in 2003, Alberta's Water for Life Strategy through s. 7 (Alberta Government 2013). A Water Management Plan for the South Saskatchewan River Basin has been established for the study area which addresses the issue of full allocations and includes the water resources of the Bow, Oldman, and South Saskatchewan River sub-basins; however, no real mention of climate change is made (Alberta Environment 2006). Further complicating this management instrument is the creation of land-use frameworks through the Alberta Land Stewardship Act administered by a Land-Use Secretariat. A Draft South Saskatchewan Regional Plan relates to the case study area and does mention climate **change** and refer to other pieces of legislation (Alberta Government 2013); this area does not align with the watersheds and the regions of the Watershed Planning Advisory Councils. Further, the land-use framework plan is advisory and not binding, so it is unclear how influential at the end of the day this document will be. However, the municipalities participate in the drafting of the water and integrated land-use plans such that jurisdiction is truly on a regional basis. In Saskatchewan as well, land-use planning has been conducted through the Ministry of Environment of the Government of Saskatchewan, while source water protection more recently facilitated by the Saskatchewan Water Security Agency through local watershed groups. As a result, the issue of "territory" and source water is not integrated.

Conclusion

Although the international positions of Argentina and Canada are very different, many similarities in climate change laws and policies exist at the regional levels. Internationally Canada officially is not legally bound to emission reductions but appears committed to a target. Argentina on the other hand has claimed entitlement to increasing its GHG emissions through the principle of common but differentiated responsibility. The positions of each country are situated within the discourse that exists at the international level surrounding global justice and developing and developed countries. The situation at the national and regional levels of each country is in contrast to this and quite similar.

Although Canada has reported reductions in emissions through regulatory efforts, very little legislation has been enacted and no commitment made to carbon taxes. The province of Alberta has legislation in place but Saskatchewan, like Canada, is without a solid legislative framework. In Argentina, several financial tools exist to assist with emission reductions as well as a glacier preservation law but only at the national level. Far from reducing emission targets, at the provincial level of Mendoza, two agencies operate with financial constraints attempting to meet the challenge of climate change. One institution operates within a resource conservation framework; the other embraces an agriculture development orientation. Institutional adaptation in both countries is oriented to "maintaining the same" in respect of development and resulting emissions, both of which are increasing.

The relatively sparse progress in passing and implementing laws and policies in relation to climate change may be as a result of a fragmentation that exists in relation to institutions within the governments at the national, provincial, and regional level in responding to climate change. This fragmentation also means that the real problems of climate change and global change, drought, and water scarcity are not dealt with. Further, a clear inequity between small and large producers is continuing to increase in both Argentina and Canada.

Institutional silos have also been created within government organization. Firstly, climate occupies a very shallow position with institutions appearing more on paper in form than substance. Water agencies and agricultural departments operate within a model of production together with a goal to increase agricultural export instead of adaptation to climate change and mitigation of GHGs. In a similar manner, this model of production results in small producers being further marginalized as the impacts of a changing climate are experienced. Lastly, the territory, or land-use planning, is once again separated from concerns of climate and water and also contains a dominant theme of increasing production. This situation questions the utility of many tools such as Integrated Water Management or Integrated Natural Resources Management that works very well in a conceptual level but experiences serious inconsistencies when put into practice.

Although both Canada and Argentina have been developing many global change policies since the UNFCC C commitments and have demonstrated progress, especially in mitigation strategies, only small gains in legislative implementation have been made. However, regarding adaptation policies, the national political strategy in both Canada and Argentina is oriented to how to fit the extractive agriculture model with new and future climate conditions. This current development strategy followed by both countries appears to be worsening the problem of climate change. Obviously this strategy is problematic, and it is questionable that maintaining the same strategy in the context of harsher climate conditions is feasible. A serious increase of an already existent vulnerability is the most certain scenario. Global change institutions move as if they weren't aware of this situation; they move by parallel paths that hardly meet. The close link between global change policy and development policy in Argentina and Canada generates unsustainable effects on the climate and natural resources and emphasizes economic inequalities between actors whose livelihoods depend on them.

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National Adaptation Planning: Lessons from OECD Countries

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Contents

Abstract

National governments have a crucial role to play in facilitating preparations for the effects of climate change. This chapter provides an overview of adaptation planning and implementation at the national level in member countries of the Organisation for Economic Co-operation and Development (OECD). It compares different approaches and discusses emerging lessons learnt and challenges

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faced based on a survey of OECD countries' National Communications to the United Nations Framework Convention on Climate Change and discussions at a workshop with adaptation policy-makers from 25 developed countries, held by the OECD in 2012.

Finland was the first OECD country to publish its strategy in 2005 and, since then, a further 17 OECD countries have published national strategies to coordinate and communicate their approach to climate change adaptation. Of the remaining OECD countries, eight have plans or strategies under development. The OECD workshop revealed three emerging challenges faced by countries as they move from planning to implementation: addressing capacity constraints, securing adequate financing, and measuring the success of adaptation interventions. Addressing these challenges will be essential to ensure that progress in planning translates into being better prepared for the effects of climate change.

Keywords
Adaptation • Climate change • National planning • Risk management

Introduction

National governments have a vital role to play in determining their countries' success at preparing for the effects of a changing climate. This can be through action, such as raising awareness of the likely effects of climate change, or inaction in the face of policies that provide the wrong incentives to individuals or businesses. Examples of the latter include insurance schemes that encourage excessive development in high-risk areas or underpricing of resources that will become scarcer in the future. Increasingly, governments are using national adaptation planning to provide an evidence-based, coordinated, and systematic approach to their preparations for climate change.

Much of the policy and academic literature on adaptation to date has focused on developing countries, because of their high socioeconomic vulnerability to climate change. However, a growing body of activity and experience of adaptation planning in OECD countries has shed new light on existing challenges. Finland was the first of the 34 member countries of the Organisation for Economic Co-operation and Development (OECD) to publish a national adaptation strategy. Since then, a further 17 OECD countries have developed national adaptation strategies or plans. These have focused on mainstreaming climate risks into local and national policies but with variation in the policy instruments being used, the role of the state, and the assignment of responsibilities between national, state, and local governments.

This chapter provides an overview of the current status of national planning activities and remaining challenges in OECD countries. These countries have made different choices about the degree of central direction, the balance of public and private provisions, and the arrangements for financing adaptation. National governments in federal countries and those with strong local autonomy face different opportunities and constraints than those with more centralized systems. Given this variety, this chapter draws upon the experiences of OECD countries to identify emerging lessons. It is intended to help inform the development and refinement of adaptation policies within OECD countries but also to be informative for developing countries as they develop and implement national adaptation plans (NAPs).

This chapter is organized as follows: "Status of National Adaptation Policies in OECD Countries" examines the record so far in implementing adaptation strategies within OECD countries, drawing on discussions at the *Policy Forum on Adaptation to Climate Change in OECD Countries* in May 2012 and a review of countries' National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) and complementary sources. "Emerging Lessons Learnt" builds on the review of OECD-wide progress to identify some of the lessons learnt from the design and implementation of adaptation programs and their implications for the future.

Status of National Adaptation Policies in OECD Countries

At the international level, adaptation has taken its own prominent place alongside mitigation within climate negotiation processes and is likely to be a critical component of the post-2015 international climate regime. Similar signs of progress can be seen at the national level within OECD countries. This section surveys the current levels of activity across the 34 OECD countries, updating and expanding an earlier analysis by Gagnon-Lebrun and Agrawala (2006).

Overview of Relevant Literature

A major element of the adaptation literature has aimed to provide recommendations on what planning ought to consist of and how governments ought to enact adaptation plans. OECD (2009) provides guidance on integrating climate change adaptation into development cooperation at the national, sectoral, and project levels (OECD 2009). Although targeted at developing countries, the underlying approach of applying an integrated approach to adaptation is consistent with that adopted in OECD countries. The World Resources Institute developed a framework for national adaptive capacity that can be used to evaluate countries' progress and to identify priorities for improvement (World Resources Institute 2009). This framework evaluates institutional arrangements based on their performance in providing five functions: vulnerability assessment, prioritization of measures, coordination, information management, and climate risk management.

These frameworks and guidance have been complemented with analyses of progress to date with respect to national-level planning and implementation of adaptation policies. Gagnon-Lebrun and Agrawala (2006) assessed activity in Annex 1 (developed) countries, largely based on an analysis of National Communications to the UNFCCC. Their review found that adaptation received limited attention relative to mitigation and that countries were at the stage of identifying generic options for responding to climate change rather than formulating comprehensive, mainstreamed adaptation strategies.

More recent studies have looked in greater depth at subsets of OECD countries. These have primarily focused on European countries but some have also included non-European OECD countries, for example, Australia and the United States (Bauer et al. 2011; Preston et al. 2011). Swart et al. (2009) provide an in-depth review of development processes for European countries' national adaptation programs, focusing on six areas: motivating factors for strategy development, research and scientific assessment, communication and awareness raising, multilevel governance, integrating climate change adaptation into sectoral policies, and monitoring and review of adaptation policies. The review identifies several typical strengths and weaknesses in adaptation strategies. The strengths include targeted research and good planning for implementation, review, and funding; weaknesses include a lack of coordination between sectors and unclear allocations of responsibilities between different administrative levels. Preston et al. (2011) further highlight institutional and capacity challenges to implementation.

Other reviews have focused on particular aspects of implementing adaptation policies. Bauer et al. (2011) examines coordination and integration in ten OECD countries, both horizontally across policy sectors and vertically across jurisdictional levels. They find that vertical coordination is usually addressed earlier in federal political systems than in unitary systems but that this difference fades as national adaptation strategies are developed. Westerhoff et al. (2011) analyze the relationships between national-level policies and local-level actions in four European countries. The authors note that national political support and leadership are key factors in the development of national adaptation activities but highlight some regional- and city-level activities that developed in the absence of specific national initiatives. They attribute some of these subnational activities to facilitation through climate change networks.

A common feature of the comparative literature is the emphasis on description rather than evaluation, reflecting both the newness of the field as well as a lack of consensus about the most appropriate approaches for implementation and criteria for judging success. While there is agreement over many of the broad principles for efficient adaptation (such as the need to account for uncertainties), there are still a range of views about how those principles should be put into practice. Swart et al. (2009) stated that it was not possible to provide policy recommendations at the time of their analysis because of the variation between countries' adaptation priorities, climate impacts, and political systems. It cautions that measures that have been successful in one context may not be directly transferable to other countries.

Overview of Progress to Date

This section provides an overview of the status of activities across the OECD as of March 2013, updating the analysis originally undertaken by Gagnon-Lebrun and Agrawala (2006). It uses a survey of National Communications (NCs) to the UNFCCC as the initial source of information on the extent of activity that is underway within OECD member countries.

NCs have three characteristics that make them a useful starting point for this analysis (Gagnon-Lebrun and Agrawala 2006). The first is that they have comprehensive coverage. All OECD member countries have submitted at least one report, and 29 countries published their fifth NCs in 2009 or 2010. For the remaining OECD members – Chile, Israel, Korea, Mexico, and Turkey – the analysis is based on their most recent NCs. Chile, Israel, Korea, and Mexico are the only OECD member countries that are classified as "non-Annex 1" countries under the UNFCCC. This means that they are considered as developing countries and that their NCs are not subject to in-depth expert reviews. Turkey is an Annex 1 country but has only published one NC. The second reason for using NCs is that their format is standardized, which facilitates comparison between countries. The third is that they are official statements and, as such, should reflect the government's perspectives and priorities.

The approach adopted for this section has been adjusted to address the limitations with using NCs as a sole data source. NCs may not fully reflect the progress to date within their respective countries (Gagnon-Lebrun and Agrawala 2006). Some elements may be missed because the NCs are intended to provide an overview of the main activities underway, rather than an exhaustive account of all the adaptation activities taking place within a country. Additionally, the majority of NCs included in the analysis were published in 2009 or 2010, which means that they may precede some important recent developments. Complementary sources of information were used to identify completed and ongoing activities relating to the establishment of institutional mechanisms for adaptation responses and the formulation of adaptation policies that were not identified in the NCs. These sources of information included: documents available on the Climate-Adapt website for EU member states (http://climate-adapt.eea.europa.eu/) and follow-up by email with government officials.

The review, presented in Table 1, is based on a qualitative analysis of every OECD country's NC, assessing eight components of national adaptation planning with regard to both the *scope* and the *depth* of coverage. The assessment of the scope of discussion is based on the level of attention paid to the topic, classified as: (i) extensive, (ii) limited, or (iii) not included. The assessment of the depth of coverage is based on the quality of the discussion: (i) detailed, (ii) generic, (iii) limited, or (iv) not included.

Where there was no coverage of activities for a specific component within a country's NC, but complementary sources indicated that actions had been taken or are currently underway, these additional activities have been identified in the table using cross-hatching.

The analysis distinguishes between two different levels of planning: adaptation *strategies* and adaptation *plans*. In this study, adaptation strategies refer to countries' initial planning or framework documents, which commonly set out governmental approaches to adaptation and communicate general priorities. Adaptation plans refer to more substantive planning documents that identify specific policies and measures to be taken. This division is reflected in Table 1, which groups countries into four subcategories: (i) those that have not published an adaptation strategy, (ii) those that have not published a strategy but have taken significant national action, (iii) those that have published a strategy but not a full adaptation plan, and (iv) those that have published both a strategy and a plan. The distinction

Table 1 Coverage of adaptation in National Communications

			Impact assessments			Adaptation options and policy responses				
			Historical climatic trends	Climate change scenarios	Impact assessments	Identification of adaptation options	Mention of policies synergistic with adaptation	Establishment of institutional mechanisms for adaptation responses	Formulation of adaptation policies/ modification of existing policies	Explicit incorporation of adaptation in projects
No adaptation strategy published		Czech Rep. *	●	●	●	●	○		○	
		Estonia *	○	○	●	○	○			
		Greece	●	●	●	●	●			
		Iceland	●	○	●					
		Israel *	○	○	●	●	○	○	●	
		Italy *	●	○	●	●	●		○	○
		Japan	○	●	●	●	○		○	
		Luxembourg	●	○	○				○	
		Poland *	○	●	●	○	○			
		Slovak Rep. *	●	●	●	●			○	
	Actions without strategy	Canada	○	○	●	●	○		●	○
		New Zealand	○	●	●	●	○	○	●	
		Norway *	●	●	●	○	○	●		
		Slovenia *	●	○	●	○			○	
		Sweden	○	●	●	●	○		○	
		United States	●	●	●	●	●		●	
Adaptation strategy published	No adaptation plan published	Australia	○	●	●	●	○	●	●	
		Belgium **	○	●	●	●	●		●	
		Chile **	○	●	●	●	○		○	
		Hungary **		●	○	○			○	
		Ireland **	●	●	●	○	●		○	
		Portugal **	●	○	○	○		●	○	
		Switzerland **	●	●	●	○	●	○	○	
		UK **	○	○	●	●	●	●	●	○
	Adaptation plan published	Austria	○	●	●		●			○
		Denmark	●	●	●	○	○	○	●	●
		Finland	●	○	●	●	●	○	●	○
		France	●	●	●	○	●		●	
		Germany	○	○	●	○	○		●	○
		Korea	●	●	●	●	●		●	
		Mexico	●	●	●	●	●	○	●	
		Netherlands	○	○	●	●	○		●	●
		Turkey	●	●	●	○				
		Spain	○	●	●	●	●	○	●	

(*continued*)

Table 1 (continued)

Legend

Coverage in NCs:

(dark grey)	Extensive discussion
(light grey)	Some mention / limited discussion
(blank)	No mention of discussion

Coverage in complementary sources:

(red horizontal lines)	Activities discussed in other sources
(blue vertical lines)	Activities currently underway
*	Developing a national adaptation strategy
**	Developing a national adaptation plan

Quality of discussion in NCs:

●	Discussed in detail, i.e. for more than one sector or ecosystem, and/or providing examples of policies implemented, and/or based on sectoral/national scenarios.
○	Discussed in generic terms, i.e. based on IPCC or regional assessments, and/or providing limited details/no examples/only examples of planned measures as opposed to measures implemented.

Source: Based on National Communications, supporting publications and complementary information, as of March 2013

between strategies and plans is necessarily imprecise; countries' adaptation planning documents vary widely in their coverage and concreteness. Also, the table only includes national-level documents that target the main climate change impacts (the composition of sectors will depend on specific country contexts). Some countries have published subnational adaptation strategies or plans concerning specific sectors or geographic regions, which can contribute to preparations for climate change but are not included in this analysis.

There has been progress since the review undertaken in 2006 by Gagnon-Lebrun and Agrawala. Table 1 shows that all countries provide information on climate change impacts and future scenarios in their NCs, which was not the case in 2006. According to the current review, 31 countries cover adaptation options in their NCs, compared to 16 OECD countries in 2006 (Gagnon-Lebrun and Agrawala 2006). There has also been significant activity in developing adaptation policies – 27 OECD countries mention policies that are synergistic with adaptation (compared with 13 in 2006), and 27 countries discuss specific adaptation policies or the modification of existing policies to include adaptation (compared with five in 2006). The scale of activity in this area becomes even more apparent when additional sources of information are considered. According to this, 8 of the 16 countries without strategies are currently developing them. All but one of the countries with strategies have either developed or are developing plans.

Emerging Lessons Learnt

The previous section provides an overview of the reported level of activity across countries, but countries with similar levels of activity may adopt substantively different approaches. These differences reflect varying political, social, and geographical contexts, needs, and priorities. Countries with federal systems or strong localized decision-making processes, such as Australia and Norway, have produced overarching strategies for adaptation that establish frameworks within which local adaptation efforts can be implemented. In contrast, unitary states have tended to produce national plans that outline specific adaptation policies and measures for different sectors or geographic areas. Overall, there is a growing volume and a growing diversity of experience to draw upon from OECD countries.

Based on OECD countries' experiences at varying levels of adaptation planning, this section outlines some of the key areas identified by participants at the 2012 workshop.

Evidence Provision

OECD countries have demonstrated significant advances in evidence gathering and in providing tools to assist end users in making use of increasingly sophisticated climate information. Nonetheless, the policy-makers at the 2012 workshop identified two main unresolved issues: developing capacity for adaptation among key decision-makers and reconciling the needs of users with the evidence that can feasibly be supplied.

Capacity for Adaptation

Providing information on climate change and improving decision-makers' capacity to use that information is a central focus of adaptation strategies in OECD countries. Mainstreamed approaches depend upon the relevant decision-makers being aware of the need to consider climate change but also having access to the data and tools required to do so. Investments in climate projections and impact assessments are necessary, but not sufficient, for achieving this (Pfenninger et al. 2010; Swart et al. 2009; Westerhoff et al. 2011).

There is a continuing mismatch between the types of climate information and data available and those required to meet policy-makers' needs (OECD 2012). For example, it is currently very difficult to model the variations in microclimates across mountainous regions, but understanding these variations is essential for disaster risk management. Part of the challenge lies in the tension between the requirements of decision-makers for greater technical sophistication while also ensuring that the outputs are accessible to end users. Progress on the former has been more rapid than on the latter, sometimes reflecting a lack of communication between researchers and end users. In some countries, "boundary organizations," such as the United Kingdom Climate Impacts Programme, have been created to bridge the gap between producers and consumers of knowledge.

OECD countries have adopted a number of approaches to increase capacity for climate change adaptation. For example, Mexico has established a distance learning program to enhance the capacity of subnational-level municipal staff. The United States White House Council on Environmental Quality has issued guidance to United States federal departments to support their development of adaptation policy statements and departmental plans, while supportive working groups and a practitioner-level community of practice facilitate information sharing and capacity development. The United Kingdom's adaptation program has supported the development of multiple tools to assist private actors in making adaptation decisions. This includes the *Adaptation Wizard* and *Business Areas Climate Assessment Tool* developed under the UKCIP. However, despite these clear examples of measures to build capacity, workshop participants felt that there was a continuing need for OECD countries to apply a systematic approach to capacity development.

Strategic Planning

OECD governments have taken a variety of approaches to the processes of achieving national coordination, mechanisms for soliciting stakeholder input, institutional structures adopted, and approaches to prioritizing measures. A clear lesson from this experience is that a strategy document alone is not enough to direct national adaptation. The structure and components of the document are important, but there also need to be effective mechanisms in place to implement the strategy (OECD 2012).

National-Level Coordination

Improving the coordination of adaptation actions is a central aim of adaptation planning, but adaptation *plans* and *strategies* differ in how this is achieved. Adaptation plans typically contain greater detail on adaptation needs and measures, including responsibilities for different actions. This makes it more comparatively clear to assign roles and identify coordination needs for those specific actions. In contrast, adaptation strategies have a different set of needs for coordination. As strategies tend to describe activities and objectives in broader terms, there is a stronger need for general coordination mechanisms to achieve progress. A common approach taken in OECD countries, both for adaptation strategies and plans, has been to establish a central coordinating mechanism to oversee and direct adaptation. Coordinating units vary across countries in terms of the parties involved, their remits and their powers; they include interministerial committees, working groups, and task forces. Of the 24 OECD countries that have established coordinating units, 21 have been led by environment or climate change departments; the exceptions are Hungary, Norway, and the United States.

In the context of developing countries, OECD (2009) recommended that coordination be led by an executive office, in order to provide adaptation efforts with sufficient convening and leadership powers to effectively coordinate actions across departments or sectors. This recommendation was also made by the Independent Evaluation Group's assessment of the World Bank's interventions to support adaptation (IEG 2012). The rationale being that in many countries the environment or climate change departments may be in a weaker position relative to other departments, such as planning or finance. These imbalances – both in terms of political power and funding – can create barriers to sustaining political support for adaptation across government. This can make it more difficult to maintain adaptation objectives in the long term and to negotiate sustainable financial support over time within budget allocations.

However, an advantage of coordination by environment or climate change ministries is that they are likely to be the most aware of the technical requirements of national adaptation plans. For example, French government officials reported that relocating the body responsible for adaptation planning from the prime minister's office to the environment ministry in 2007 helped it to address operational issues and to increase collaboration. Additionally, locating responsibility within a central ministry does not in itself guarantee long-term political or financial support. It may well be a lower priority for central ministries themselves than it would be in a dedicated environment department, which can offset some of the benefits of being in a politically stronger ministry. The experience of OECD countries has not demonstrated a consistent relationship between the location of the coordination unit and the effectiveness of adaptation policy.

The existence of high-level formal structures, such as ministerial coordination groups, can be a weak proxy for the degree of on-the-ground coordination. Given the recent implementation of many countries' national adaptation programs, it may be too early to evaluate coordination groups' effectiveness beyond their initial success in convening representatives from different departments. However, the challenges that these mechanisms are intended to overcome – addressing crosscutting issues and managing cross-departmental actions – require a firm grounding in adaptation policy. This issue is especially pertinent for countries with technical adaptation plans that specify required outcomes and measures for different departments and/or sectors. Some OECD member countries have found it valuable to complement high-level coordinating with working-level groups to provide technical direction. For example, the United States adaptation working group and practitioner-level community of practice support the higher-level coordinating efforts of the Interagency Climate Change Adaptation Task Force.

Stakeholder Engagement

There is inevitably a strong technical element to national adaptation planning, but it is not a purely technocratic process. Policy-makers viewed it as essential to involve a broad set of stakeholders at strategic planning and policy design stages to assist the development of national programs (OECD 2012). As well as improving the quality of policy-making, the process of stakeholder engagement can be useful for raising awareness and interest among key groups. A common feature of national adaptation planning has been the establishment of comprehensive consultation processes to solicit input from key stakeholders and the general public. For example, Austria sought additional stakeholder input for its national planning through expert consultation, an extensive round of workshops with relevant organizations and internet-based engagement. Several countries have relied upon umbrella or intermediary organizations to facilitate the consultation process, given the large number of potential stakeholders. The benefits of this approach are particularly marked when interacting with large, dispersed groups of stakeholders such as the general public or small businesses. The use of intermediary organizations has also been driven by pragmatism, as smaller stakeholders tend to have less capacity to engage with the process (Bauer et al. 2011). In the United Kingdom, the adaptation program partnered with the Confederation of British Industry and the Trades Union Congress to solicit input from employers and employees, while also raising awareness and disseminating guidance.

Identifying and addressing the needs of indigenous groups is a particular concern in some OECD countries. Indigenous groups, who often face significant social and economic challenges, are likely to be at particular risk due to climate change (International Union for Conservation of Nature 2008; Galloway McLean et al. 2009). Indigenous groups may also be less well represented in traditional stakeholder engagement processes (Gardner et al. 2010). In the United States, the Environmental Protection Agency developed a policy statement and plan to ensure consultation and coordination with Indian tribes (Environmental Protection Agency 2011). Although there has been progress made through initiatives such as this, ensuring appropriate engagement and input from indigenous groups remains a challenge for some countries.

Program Structure

In designing their national adaptation programs, OECD countries have had to choose how to organize the delivery of adaptation actions: either mainstreamed within existing departmental portfolios or addressed thematically (e.g., “infrastructure” or “water”). Aligning adaptation to existing departmental responsibilities may help to ensure clear accountability for results but may come at the risk of making cross-departmental interactions less frequent – for example, those between land-use planning and flood risk management. In principle, these interactions should already be addressed by existing policy structures, but in practice this is often not the case. Encouraging integration is particularly important during the development of plans or strategies, as adaptation needs can fall between traditional departmental operations or face overlapping or contradictory approaches from different departments (Bauer et al. 2011). Crosscutting thematic approaches may better enable policy-makers to deal with these critical interactions. This choice is important for setting the direction of both adaptation strategies and adaptation plans. However, the greater level of detail on actions and policies in adaptation plans requires a more thorough examination of organizational responsibilities and greater specificity on responsibilities for implementing actions.

The most common approach in OECD countries has been to combine elements of the two approaches in “sectoral” national programs (though definitions of sectors are flexible and vary across countries). For example, the federal approach in the United States has developed along departmental, regional, and thematic lines. In 2012, federal agencies were required to develop agency-level adaptation plans. In addition to these plans, three national-level strategies that address crosscutting issues (such as the management of freshwater resources) have been developed or are in the process of being developed, and there are a number of other regional initiatives and partnerships. England’s approach initially closely aligned adaptation roles to traditional ministerial responsibilities, with each individual government ministry responsible for developing Departmental Adaptation Plans. However, the forthcoming national adaptation plan will move towards a more thematic approach (UK Department for Environment, Food and Rural Affairs 2012). Mexico's Special Program of Climate Change is based on a combination of departmental and thematic sectors, including a mix of economic sectors (e.g., "agriculture, cattle, forestry, and fisheries"), social concerns (e.g., "health sector"), and crosscutting issues (e.g., "land-use management and urban development" and "disaster risk management"). A number of other OECD countries are also pursuing mixed sectoral approaches, including Chile, Korea, Poland, and Turkey.

Regardless of whether governments take a departmental, thematic, or sectoral approach, coordinating activities within adaptation programs poses a key challenge. Under a thematic approach, governments have to coordinate measures across departments to ensure that thematic goals are met, generally using central coordination groups or mechanisms. Lessons can be learnt from other fields of public policy that face similar coordination challenges. For example, there is a growing body of work in the water policy domain to address issues such as overlapping and unclear allocations of responsibilities, lack of institutional incentives for cooperation, mismatches between impact areas and administrative boundaries, and competition between different departments (OECD 2011).

Prioritization

The selection and prioritization of adaptation options are an essential part of adaptation planning. Governments need to identify the impacts likely to be most socially and economically significant. They also need to prioritize specific issues or actions to ensure an efficient use of public resources. The specific challenges faced by governments depend upon the planning approach taken. In theory, adaptation strategies do not need to include prioritization of vulnerabilities or responses. The key activities proposed in strategies (such as improving the evidence base, capacity building, and mainstreaming adaptation within government activities) do not depend upon the precise details of the climate change impacts faced by the country. In practice, however, adaptation strategies often include some prioritization, in part to communicate important risks or vulnerable sectors. As adaptation plans include greater detail on specific activities and measures, they require a better understanding of key risks and of the options for addressing them. Prioritization is therefore a critical component of adaptation plans and needs to be more comprehensive and based on firmer technical foundations than in adaptation strategies.

Several promising approaches for prioritization have been developed within OECD countries. The approach used by Switzerland identifies key adaptation challenges within individual sectors. This approach uses three criteria to produce an overall "importance" ranking: (i) whether an issue is sensitive to climate change impacts, (ii) whether the impact is important relative to other impacts within the sector, and (iii) whether there is a need for action to address the issue. This ranking feeds into the identification of action areas and key priorities in their strategy (Office Fédéral de l'Environnement 2012). The United Kingdom government's prioritization system draws on their Climate Change Risk Assessment study, which enables the government to identify key climate change risks and to prioritize adaptation policy development both geographically and by sector. This information feeds into the high-level adaptation planning process. Thus, policy development, both for the current program and for the national adaptation plan, is geared towards addressing the critical issues identified. Some governments have also established criteria for choosing between individual adaptation policy options. For example, the Netherlands' national adaptation program used a multi-criteria analysis approach to rank a wide range of adaptation policies according to five criteria: (i) the importance of the policy, (ii) the urgency of the policy in terms of timing, (iii) whether it is a "no-regret" policy, (iv) whether the policy has ancillary benefits for non-climate change policies, and (v) the policy's impact on mitigation policies. Each criterion is weighted according to perceived importance to produce a weighted sum value for ranking policy options (Ministry of Housing, Spatial Planning and the Environment et al. 2007; van Ierland et al. 2007).

Countries' prioritization systems vary in their choice of criteria, the level of importance attributed to each criterion, and the extent to which prioritization is based on quantitative or qualitative inputs. Some of this variation is accounted for by different prioritization needs for adaptation strategies versus those for adaptation plans. For instance, the issue of quantitative versus qualitative decision making is particularly salient for adaptation plans. The lack of sufficient or suitable projections of climate impacts is a key challenge for developing adaptation plans (OECD 2012). This poses less of an issue for adaptation strategies, as they tend to be less specific than plans about the measures to be implemented. It was, however, noted that the lack of climate impacts data does not need to delay the development of national adaptation plans. The evidence base will never be perfect and the benefits of waiting for improved information must be balanced against the costs of delay. As with other areas of public policy, the challenge for policy-makers is to make the best decisions given the available evidence.

Implementation

The overview of national adaptation planning in OECD countries in the section "Status of National Adaptation Policies in OECD Countries" shows that there has been progress in the planning of adaptation but that implementation remains at an early stage. This section examines countries' implementation experiences in two specific areas: financing of adaptation and monitoring of implementation.

Financing the Implementation of Adaptation Measures

There is a choice about how to fund adaptation measures, either through mainstreaming or the use of "ring-fenced" funding. Dedicated funds provide an impetus for action on adaptation but can distort spending decisions and work against coordination with wider government objectives. Conversely, mainstreamed approaches should allow for a more flexible and efficient use of resources but are much less transparent about where resources are being allocated.

Although estimates vary widely, the global costs of adaptation are likely to be in the order of tens to hundreds of billions of United States dollars per year (Parry et al. 2009). Even at the lower end of this spectrum, funding is likely to be a significant hurdle to implementing effective adaptation policies and measures. Securing financing for adaptation programs is therefore a key concern for policy-makers and a key challenge to be addressed in adaptation programs. As in other policy areas, challenges will differ at different stages of adaptation planning. Given their broad focus on improving the evidence base, building capacity and creating an enabling environment for adaptation, strategies have required relatively modest funding for initial climate information and capacity building activities. Adaptation plans, which set out specific actions and establish responsibilities for implementation, ought to be based on an understanding of the likely costs of measures and their benefits. This ensures that funding is sufficient and that the chosen adaptation options represent good value for money.

Few OECD countries specify how their adaptation programs will be funded or the scale of resources required for implementation. Of those that explicitly mention funding, they predominantly focus on preliminary activities such as vulnerability assessments and climate research, rather than the implementation of measures. England's adaptation program has allocated some core funding for adaptation research but has been designed on the basis that the funding of adaptation measures will be achieved by reallocating existing resources. France has estimated the costs of adaptation measures at €171 million per year, but these are expected to be delivered through the usual budgeting process. Mexico's Special Program on Climate Change identifies investment priority areas, but does not specify how such investments would be funded. The United States' program also does not specify how adaptation should be funded, but leaves the financing to individual departments.

The lack of clarity on financing can, in part, be explained by the short time adaptation has been on the policy agenda. Additionally, the focus on mainstreaming in most strategies and plans reduces the need to discuss specific funding mechanisms, as actions are expected to be funded through existing departmental budgetary processes (OECD 2012). Limited details on the actual costs of many adaptation options can also complicate discussions around financing needs and value for money (Biesbroek et al. 2010). Lastly, given current fiscal pressures, the limited discussion of funding in adaptation plans may be a reflection of the limited scale of public resources that are likely to be made available.

Countries' experiences in implementing adaptation also suggest actions that can increase resource availability and maximize the impact of those resources that are available. These include building government support for adaptation by ensuring that adaptation aims are linked to current government priorities (notably economic growth) and by proposing adaptation options that serve multiple purposes and have multiple benefits (OECD 2012). Additionally, participants recommended adapting policy instruments or regulations that are already in place, rather than starting from scratch. Financial constraints have also encouraged governments to engage the private sector in adaptation. As a starting point, governments have started to encourage the private sector to secure its own resilience to climate change (Agrawala et al. 2011), which ought to reduce the need for public investments in adaptation.

Monitoring and Evaluation of National Adaptation Strategies

As countries implement adaptation programs, they will also need to track the effectiveness of actions and the outcomes of adaptation interventions. Sophisticated approaches to monitoring and evaluation (M&E) are currently being developed in Finland, France, Germany, and the United Kingdom. A common characteristic of these frameworks is their initial focus on monitoring progress in creating the right enabling environment for adaptation (Swart et al. 2009). In essence, this entails a focus on monitoring processes (e.g., the number of government departments that have assessed their exposure to climate risks) rather than outcomes (e.g., reductions in vulnerability to climate change). However, regular monitoring must be complemented by longer-term evaluations that examine if set objectives have been achieved, whether these objectives are still valid in the light of new evidence, and if the identified results can be attributed to the adaptation actions taken.

Participants at the policy-makers workshop noted the challenges involved in conducting M&E assessments, including generating baselines for use in assessing progress, attributing causality of outcomes to actions, the high costs of data gathering, and the long time horizons of climate change. Given these challenges, most countries are not yet in a position to evaluate the effectiveness of adaptation efforts using outcomes-based approaches. However, certain M&E approaches can help governments to address these issues. Notably, the United Kingdom's approach combined progress and outcome indicators and should help in making the connection between adaptation policies and observed outcomes. The frequent snapshots of vulnerability provided by the United Kingdom's five yearly Climate Change Risk Assessments (CCRA) are expected to help policy-makers assess progress and provide updated baselines against which adaptation interventions can be assessed. Vulnerability assessments such as these may give countries a means of assessing the broad effectiveness of adaptation programs, as a complement to or in support of tracking the effectiveness of specific adaptation measures.

France's M&E strategy provides an alternative approach intended to help overcome technical and financial challenges to evaluation. France's approach uses existing tools and procedures to review progress. It combines comprehensive monitoring of the implementation of measures (using both process and outcome indicators) with targeted evaluation of key sectors using a range of evaluation techniques, such as impact assessment, cost-effectiveness, and cost-benefit analysis. It also includes a qualitative review of climate change preparedness before and after adaptation interventions. This approach should reduce the need to develop new technical evaluation techniques and the associated costs and challenges with gathering data.

While addressing political and technical challenges in the design and implementation of M&E approaches is critical, policy-makers emphasized the importance of ensuring that the results from M&E assessments feed into the development and evolution of national adaptation programs. This requires both continuous learning (such as regular assessments or periodic reviews) and feedback mechanisms that outline how M&E results, and new information will contribute to ongoing planning and implementation processes (Pringle 2011). To facilitate this, some OECD countries have provided a statutory basis for periodic reviews. For example, in the United Kingdom the 2008 Climate Change Act requires a review of the national adaptation program every 5 years. In Finland, the national adaptation strategy underwent a midterm review in 2009, with a more comprehensive review scheduled for the 2011–2013 time frame. Similarly, there will be a midterm review of the French national adaptation plan in 2013, which will feed into the development of the next plan for 2015, and the Danish strategy will be revised before the completion of its implementation phase at the end of 2018, drawing on annual reports produced by a national coordination body (Swart et al. 2009).

Conclusion

Overall, there has been considerable activity since the 2006 stock take of activity in OECD countries. In 2006, the National Communications focused on discussing projected climatic changes and the resulting impacts. There were some examples of stand-alone adaptation projects but limited evidence of coordinated approaches being adopted (Gagnon-Lebrun and Agrawala 2006). As of May 2013, the majority of OECD countries have started the process of national planning for adaptation: 18 countries have implemented strategies or plans, and a further eight are in the process of producing them. Some of the remaining countries have put in place systems for national coordination, as in the United States, or focused on enabling local and regional action, as in Canada, without articulating their strategies in a single document.

OECD countries have made significant investments in providing evidence and tools to inform the national planning process, for example, developing an increasingly sophisticated understanding of the potential risks of climate change and a growing volume of work on possible adaptation options. Several countries are now planning to go further than this and assess the costs and benefits of adaptation options. These investments, and the prior decades of work they build upon, have already proved a useful input into the policy-making process.

The approaches taken have reflected national circumstances, but some common themes have emerged. The first is that the financing of adaptation actions remains an area with limited evidence on the scale of resource requirements and the sources of funding. In part, this is because there is still a gap between high-level global estimates and localized studies. The costs of adaptation at the national level remain largely speculative at this stage.

The second theme is that the development of evidence on adaptation should go hand in hand with efforts to increase the capacity of end users to understand and apply those resources. Efforts to increase the technical sophistication of climate projections (and related tools) are needed to provide data that are tailored to the decisions being made. But this needs to be complemented with efforts to increase the usability of the evidence that is made available.

Finally, an area that has received limited attention to date is assessing the results of the actions that have been implemented. Economic theory provides some indication of the types of approaches that are likely to be efficient or effective, for example, adopting a flexible approach and aiming for "win-win" and "no- or low-regret options." However, there are different ways of achieving these objectives, and they will not be equally effective. Monitoring and evaluation (M&E) is important for political accountability but also for learning lessons that can be used to inform revisions to the design of programs. Even countries with plans specifying actions, responsibilities, and timescales are at an early stage in their development of M&E strategies. This limited attention to M&E partly reflects the high-level, strategic nature of many adaptation policies, where there is still more work to be done to specify the objectives and trade-offs in ways that are sufficiently detailed to enable assessments of progress.

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Political Dimensions of Climate Change Adaptation: Conceptual Reflections and African Examples

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Contents

Abstract

This chapter supports the argument that social science research should focus on adaptation to climate change as a social and political process, by analyzing the politics and interests of actors in climate change adaptation arenas and by acknowledging the active role of those people who are expected to adapt. Most conventional climate research depoliticizes vulnerability and adaptation by removing dominant global economic and policy conditions from the discussion. Social science disciplines, if given appropriate weight in multidisciplinary projects, contribute important analyses by relying on established concepts from

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political science, human geography, and social anthropology. This chapter explains relevant disciplinary concepts (climate change adaptation arena, governance, politics, perception, mental models, culture, weather discourses, risk, blame, traveling ideas) and relates them to each other to facilitate the use of a common terminology and conceptual framework for research in a developmental context.

Keywords
Climate change adaptation arena • Governance • Politics • Perception • Mental models • Culture • Weather discourse • Risk • Blame • Traveling ideas • Discourse • Development • Africa

Introduction

While the issue of climate change mitigation has received a significant amount of political and scholarly attention over the past two decades, engagement with climate change adaptation is a younger phenomenon. Although the concept was taken into consideration from the outset of the UNFCCC process in the early 1990s, adaptation gained official political momentum in international climate change negotiations only after the finalization of the *Marrakech Accords* in 2001. The reluctance to embrace adaptation as a viable policy option was partly grounded in the fear that a shift to adaptation would weaken the political will to undertake greenhouse gas reductions (Pielke 1998; Kates 2000; Burton 2009; Schipper 2006; Thornton and Manasfi 2010). The main argument that finally paved the way for adaptation was the scientific observation reported by the IPCC that climate change is already happening worldwide and that in Africa "adaptation is not an option but a necessity" because populations are already facing negative impacts (Boko et al. 2007, p. 452).

The thinking about adaptation in the context of development has also changed considerably since the beginning of the new millennium. Public discourse is now dominated by planned adaptation as a policy response to climatic risks. Adaptation to climate variability/change as a research topic has gained popularity in the natural as well as in the social science disciplines. A large and diverse variety of actors are assembling around the looming "climate catastrophe" (Hulme 2008, p. 11), both in the Global North and South. Development agencies and multilateral institutions, as well as the private sector and civil society organizations, have found their stakes in fighting global warming. And in Africa, we observe the increasing engagement of national and local governments, media, NGOs, churches, and religious and traditional leaders, who shape the politics of climate change.

Climate change has become an "unchallenged consensus" with a respective "apocalyptic rhetoric" (Swyngedouw 2010, pp. 216–218). Critics warn that climate change has become the big "environmental orthodoxy" at the turn of the millennium (Forsyth 2003, p. 36), and threatens to depoliticize the attempt to govern global warming (Swyngedouw 2010). Most climate adaptation research tends to be apolitical, without paying attention to social and political framework conditions within countries, the interests and power of the actors (Lockwood 2013), or the perceptions, priorities, vulnerabilities, and bargaining powers of the potentially affected populations. This leads to a situation where social science perspectives are underrepresented in multidisciplinary research projects on adaptation that are mostly driven by the natural sciences.

Within the social science climate and development studies community, we observe methodological rapprochements with, for example, mixed methods, ethnography, and economic survey techniques being applied by geographers and political scientists. The exchange of different theoretical and conceptual understandings to find a common or interdisciplinary language, however, is also a challenge among social scientists. This is often overlooked in multidisciplinary debates. There are, however, various ways to conceptualize multidisciplinary social sciences in climate change research (see, e.g., Baer and Singer 2014 for their critical "integrated eco-social perspective" approach, which assembles ideas from world systems theory, political ecology, and critical medical anthropology). Over the past few years, however, multidisciplinary studies on climate change have tended to demarcate fields of expertise by employing distinct terminology and publishing in *climate change* journals that seem increasingly disconnected from debates between disciplinary scholars in the social sciences.

Thus, the objective of this chapter is to *denaturalize adaptation* and to bring back "the political" (in the sense of Swyngedouw 2010) in the discussion about climate change. The chapter suggests a number of established concepts from social geography, social anthropology, and political science that are sensitive to discussing empirical findings in a multidisciplinary and developmental context. These concepts highlight the inherent political dimensions of adaptation as well as local/cultural perspectives (*emic perspectives*) on change, risk, and adaptation.

The following section on political agendas will outline the central concepts used in the adaptation debates in political science and geography. In the next section, environmental perception, blame, and risk will be discussed, along with their links to power and politics from an anthropological and geographic point of view. The concluding outlook summarizes the argument for why adaptation needs to be analyzed more often as a socio-cultural, with a focus on emic perspectives as well as on local social and political dynamics.

Political Agendas

Approaches that look at functional applications from administrative and technical perspectives seem to be on the rise. Governance, a former domain of political science, has been appropriated by other disciplines as well as the international development community. When this concept is adjusted to a climate change adaptation context, it tends to take a rather technocratic turn (Fröhlich and Knieling 2013). There are, however, notable disciplinary exceptions (e.g., Adger and Kelly 1999; Tschakert 2007; McMichael 2009; Agrawal 2010; Pelling et al. 2012;

Sheridan 2012; Bassett and Fogelman 2013) as well as multidisciplinary works that provide room for political, historical, and cultural analyses (e.g., Crane 2010; Djoudi et al. 2011; Brockhaus et al. 2012; Wisner et al. 2012).

Multidisciplinary studies show how social, political, cultural, economic, and technological circumstances shape vulnerabilities across scales and how they determine local perceptions and adaptation outcomes. Studies with a political focus also explore how socio-spatial aspects of risk and adaptation are strategically emphasized or de-emphasized by actors to legitimize their political narratives and interventions; often to serve their own interests.

Adaptation to climate change is understood as a politicized *social arena* which has been opened up by the IPCC assessment reports, the political attention these reports received globally, as well as by international funding opportunities under the UNFCCC for adaptation/mitigation planning and implementation in Africa. This has been the starting point for the evolution of *Climate Change Adaptation arenas* (*CCA arenas*) in African countries, which clearly display partial overlap and continuity with older political arenas, such as natural resources management, infrastructure delivery, or development cooperation. The *cross-scalar* and *multi-scalar CCA arenas* are very dynamic, assembling actors with diverse interests who channel flows of information and resources among each other and beyond the arena. The developmental context is characterized by uncertainty with regard to climate change, by the links between poverty and vulnerability in the potentially affected population, as well as by the hegemonic distribution of power and resources among the actors, including governments, local authorities, the public media, civil society organizations, international donors, and the climate research community. Access to information and resources is structured by the socio-cultural, political, and economic status of these actors as well as by their networks.

How adaptation is defined and implemented across multiple scales is strongly influenced by the changing interests of actors in the CCA arenas who exercise *discursive power* and are capable of dominating political negotiations, and therefore, their outcomes. Political agenda-setting is not always as transparent and straightforward as many scholars and practitioners would like it to be (Brooks et al. 2009), and *selective depoliticization* of the adaptation discourse can often be observed. Conceptualizing adaptation as an exclusively environmental problem, with some social challenges on the side of the affected populations that must be solved by applying quick technological and managerial fixes, turns a blind eye to the normative underpinnings of international adaptation and developmental discourse. For example, capitalist modes of production and consumption, the economic growth paradigm, corruption (as well as elite capture), and systemic governance failures are usually not addressed by the actors who benefit from the status quo (Bailey and Compston 2012; Brunnengräber 2013).

From a multidisciplinary social science perspective, it is useful to adopt an analytical approach that frames adaptation beyond an environmental problem with social challenges. This also means to accept that vulnerability to environmental change is directly related to “unsustainable patterns of development combined with socioeconomic inequity” (Pielke et al. 2007, p. 597). Consequently, adaptation research needs to take into account that neoliberalism operates as a form of *meta-governance* and dominates the *discursive arena* of climate change policy (Brunnengräber 2013).

Against the backdrop of the global financial crisis, the thematic focus of national and international adaptation policies has gradually moved away from ideas about environmental regulation to an emphasis on a *Green New Deal*, anchored in market-based instruments and private business solutions. Mainstreaming adaptation and *climate proofing* development projects has ultimately become a "new profit frontier" (McMichael 2009, p. 252). Payments for ecosystem services, carbon trading, crop insurance schemes, and monopoly patents on *climate-ready genes* are symptoms of the neoliberal assumption that the market is indeed the solution to environmental problems caused by a *fossilistic economy*. This idea goes hand in hand with the claim that markets should be the primary means for resource allocation. We need to ask whether it is prudent to expect market-based instruments to facilitate the adaptation of the poor and marginalized who are severely and negatively affected by climate change, when we realize that the same globalized market system is, in many parts of the world and across societies, responsible for creating poverty and local vulnerability in the first place.

This example demonstrates that multidisciplinary research on climate change adaptation needs to critically engage with emerging policy concepts that seem to offer ideological guidance and claim to countervail classical top-down policy approaches.

To extend this argument, we briefly discuss different concepts of *governance* and their normative underpinnings. The term *governance* is highly contested in academia, but has been applied in a variety of contexts, including global governance, earth system governance, public and local governance, organizational governance, corporate governance, good governance, and knowledge governance. The arbitrary use of the term has prompted many scholars of political theory to arrive at a similar conclusion. Finkelstein, especially, argues that *global governance* "appears to be virtually anything," implying that it is not a very useful concept because it lacks preciseness (Finkelstein 1995, p. 368).

Generally, there are three ways in which the governance concept is used in the literature and in public discourses. First, governance can be understood as a *scientific concept* that is employed to conceptualize and empirically trace transformations and institutionalized interventions in societies. Second, governance can be understood as a *normative program* based on the ambition to realize and manage political change. Third, governance also refers to a *critical societal discourse*, which is linked to the wider globalization debate.

These three dimensions of governance are symptomatic for the rapid changes and interactions in a globalized world. We need to make sense of the integrative and disintegrative events which occur simultaneously across space and time, which intertwine the public and the private, the global and the local, and which lead to the continuous emergence of new actor networks and regulative mechanisms that transcend the sphere of the classical nation-state. Climate change is characterized by complex and interrelated socio-economic issues that cut across jurisdictions, administrative scales, the boundaries of ecosystems, as well as fields of disciplinary expertise, and thus it requires new political approaches (Schulz 2011). Finkelstein (1995, p. 367) concludes that it is indeed "reasonable to be uncomfortable with traditional frameworks and terminologies associated with the idea of international relations in an interstate system."

However, while the conventional notion of governance identifies the nation-state as the center of political power, *multilevel governance* focuses on "the threefold displacement of state power and control: (1) upwards to international actors and organizations, (2) downwards to regions, cities and communities, and (3) outwards to civil society and non-state actors" (Termeer et al. 2010, p. 5). The idea of multilevel governance emphasizes the process character as well as the multi-scalar nature of contemporary politics. The normative bedrock of multilevel governance is the belief that the distribution of political power and responsibility across multiple jurisdictions is more efficient than classical monocentric state governance (Termeer et al. 2010).

The *fragmentation* of institutional systems and actor constellations has therefore become an important issue of governance research. Fragmentation on multiple scales is further aggravated by *multiple knowledges*, *conflicting norms*, and *scale mismatches* (e.g., between biophysical systems and governance systems), as well as by conflicting or ill-defined political mandates. Anthropologists working in Africa contribute additional observations to this picture. New decision-making bodies and rules introduced by development cooperation do not usually lead to the disappearance of existing authorities and regulations. Instead, these tend to coexist side by side (Bierschenk and Olivier de Sardan 2003). *Polycephaly* leads to a growing complexity in actors, interests, and legitimate options. It opens up the ground for strategic *forum shopping*, where people can select from available options and decide for themselves which body or authority to consult or which regulation to use as a frame of reference.

As a response to the fragmentation and *polycentrism* of governance processes, the concept of *adaptive governance* has gained increased popularity. Adaptive governance draws on systems and resilience thinking, as well as on ecosystem management approaches (Termeer et al. 2010; Plummer et al. 2013). These approaches have, commonly, an emphasis on the importance of institutional flexibility and learning for the management of complex socio-ecological systems. Adaptive governance considers temporal, knowledge, and network scales, while the concept of multilevel governance is mainly related to spatial, administrative, and jurisdictional scales. The normative goal of adaptive governance is to enhance the capacity of governance systems "to create the right cross-scale and cross-level links at the right time, around the right issues" (Termeer et al. 2010, p. 8). Adaptive governance also stresses the importance of "bridging, boundary or brokering organizations" as intermediaries in cross-scalar governance processes to enhance cross-scale interactions and networking processes, such as knowledge coproduction and conflict resolution (Plummer et al. 2013). Yet, adaptive governance may be prone to nepotism and corruption, unless there are checks and balances for the coproduction of knowledge, networking, and representation by the public media.

In other words, there needs to be a focus on political accountability as well as transparency about who gets invited to join in the political arenas and who is excluded from them.

In academia, climate change adaptation is mostly conceptualized as a subfield of *environmental governance*. Plummer et al. (2013, p. 2) describe environmental governance as a normative approach to achieve ecological sustainability and to exercise "authority over the environment through processes and institutions by which decisions are made." This theorization leads back to our earlier critique of framing adaptation as an environmental problem and de-emphasizing the social, political, cultural, and economic aspects of adaptation. Neither environmental governance nor adaptation is, in practical terms, primarily about the exercise of authority over the environment. In practice, climate change adaptation is rather a question of exercising authority over people and therefore strongly related to questions of power and politics.

Any attempt to research power and authority, however, is directly linked to the basic sociological question of *agency and structure*. Are actors, as individuals and groups, ultimately shaped and governed by structures? Or are actors able to develop their own potential for volitional and creative action? With respect to climate change adaptation, we need to answer whether political and economic structures that have caused the climate crisis in the first place can be overcome and how creative space for societal and economic transformation can be created (Driessen 2013). This is especially true in Africa, where the negative impacts of climate change already demand practical solutions, legitimate political decisions, and adaptation programs. These, as well as the degree of political inclusiveness and priorities of the affected populations, should, therefore, be of great relevance to our research. But how can we learn more about these priorities?

Perception, Blame, and Power

An increasing number of publications addresses the climate change perceptions of local communities in Africa. These *perception studies* stem largely from agricultural and economic research projects, with some multidisciplinary aspirations (e.g., Kemausuor et al. 2011; Cuni Sanchez et al. 2012). Most studies are based on data from household surveys and focus group discussions, which are compared to regional climate and weather data, such as precipitation and temperature changes. They often aim to investigate, to put it in simple terms, whether farmers perceive what scientists have measured. Many of these studies, however, are very loosely connected to the previous work done in social science disciplines and, therefore, do not contribute to a more comprehensive understanding of the mental models through which people give meaning to climate change. A number of studies conclude that farmers have a fatalistic view on climate change.

> A comparative perception study among ethnic groups in Benin revealed that "No participant mentioned the term climate change (or any similar phenomenon even described in

> other words) as a possible cause of the observed changes in climate, and no participant suggested that the trend [. . .] was sub-regional, regional or global [. . .] most farmers were found to have a rather fatalistic approach to climate concerns, with statements like 'climate is a divine phenomenon that we are not in charge of'" (Cuni Sanchez et al. 2012, pp. 122, 124).

Following Roncoli et al., who argue that instead of answering the question of whether farmers' or herder's perceptions match the "reality" of scientific findings, the more interesting questions are how knowledge and experience shape meanings of climate change and how they are integrated into their mental models (Roncoli et al. 2009).

Anthropological work on environmental perceptions in different societies worldwide has pointed out that the ways humans view their natural and social surroundings and order them into categories is culturally specific, with a lot of variation across time and space (Leach and Fairhead 2003; Casimir 2009). This is a testimony to the fact that knowing and perceiving nature are context-bound and socially constructed. The term *reception* has been used synonymously in this context (Rudiak-Gould 2012). *Perception*, however, is more adequate for the description of the process, which is not only about receiving information by seeing, hearing, smelling, or sensing. The notion of perception includes the cognitive process of constructing social meaning about the received information.

Perceptions can be analytically categorized into different elements. Strauss and Orlove distinguish between *description* and *comprehension*. The authors underscore that "the cognitive and symbolic aspects of the weather and climate deserve as much attention as the responses to specific weather events or conditions, since these two are ultimately inseparable" (Strauss and Orlove 2003, p. 6). A more detailed anthropological approach differentiates between *perception, knowledge, valuation, and response* (Roncoli et al. 2009). For the purpose of this text, we will not go into further details of psychological and cognitive studies (for a review on the mental models concept, see Jones et al. 2011).

In as much as knowledge is context specific, so are valuations and responses. Individuals valuate threats and respond in a personal way, which may differ from one person to another; however, there is usually something similar to a cultural consensus about what is commonly considered normal and good, or exceptional and worrisome. Such consensus defines what constitutes a dangerous situation, how it can be prevented, and what is required to adjust to it. In local parlance, dangerous situations are often described as a nontechnical pollution or impurity caused by *moral transgression* and can therefore be perfectly remodeled into a political argument. "Pollution beliefs trace causal chains from actions to disaster" (Douglas and Wildavsky 1983, p. 36).

> Farmers in Northern Ghana explained lack of rain with various social causes, including illegal/immoral land sales, lack of obedience for the older generation, extramarital sex, lack of united action in the community, lack of respect for ancestral spirits, laziness of some farmers, and alcoholism of a rainmaker – all examples of moral transgression. They also mentioned other causes. Moral transgression arguments, however, were prominent in the discussions (Eguavoen 2013).

Some common tendencies are found in many societies: the feeling of worry for an unknown future, the need to feel secure, and a drive to reduce uncertainty. Forecasting based on past experience is a common human process. Climate change literature discusses different models of various scales, and a distinction can be made between *climate models* in their conventional understanding and so-called mental models. "Mental models of local climate change, then, are a summative conception of all a community's climate knowledge based on their observations and experiences of past and ongoing climate variability" (Shaffer and Naiene 2011, p. 224). In addition to their contributions to ground-truth regional climate models, mental models "offer insight into changes and connections that global and regional [statistical] models cannot capture" (Shaffer and Naiene 2011, p. 235). They open up the debate for research on socio-economic transformation, stratification, and power relationships.

On a more general level, people construct culture-specific mental "model[s] of the world whose purpose it is to make predictions" to reduce uncertainty (Casimir 2009, p. 27). "[I]n most societies even before disaster strikes or while in the midst of deciding how to deal with it, people cogitate about their possible causes" (Casimir 2009, p. 29). They do so by relying on scientific models, cultural models, or, even more often, a mixture of both to explain unwanted events. These explanations assign blame to something or somebody, allowing humans to mentally survive in uncertain environments. They also form a precondition for the application of pragmatic counterstrategies.

For causal chains inherently bearing the notion of cause, responsibility, and blame, one can speak of different *models of blame*, which become relevant when the result of the causal chain is categorized as exceptional and dangerous (Eguavoen 2013). Empirically local models of blame, which we observe in rural Africa today, are often a mixed form of *cultural and scientific models* of explaining the world and its basic causal principles. Local beliefs and scientific smattering merge and usually intermingle without being in conflict with each other. By identifying the sources of nontechnical pollution, by assigning blame to culprits, or by relying on scientific explanations, people feel that they are regaining control over lives and environments that are full of danger. "To understand principles of liability, we have to uncover [. . .] social goals [. . .] and the strategies used for reaching them. For this we need cultural analysis that puts every concept of normality under scrutiny" (Douglas and Wildavsky 1983, p. 35).

> Small farmers [in Ghana] attribute social and religious/moral reasons for changing climate [. . .they] do not seem to engage in a blame game as much as the commercial farmers who find Western nations, mining companies, deforestation, charcoal burners, and poor government policies as major culprits. [Commercial farmers] assume the role of victims even though they use more land, deforest more virgin forest and appropriate a large volume of water resources for their farming purposes (Yaro 2013, p. 1265).

These findings show the cumulative effects of economic stratification, bargaining power, political inclusiveness, education, access to information, and the capability to demand governmental support. More generally, "[b]lameworthiness takes over at the point where the line of normality is drawn. Each culture rests upon its own ideas of what ought to be normal or natural [. . .] But of course the idea of normality changes with new knowledge" (Douglas and Wildavsky 1983, p. 35). Conditions that seem to suspend normality, such as during or after a hazard, may lead to exceptional and worrisome situations, which may create risky situations for people and require nonroutine behavior.

According to Casimir (2009, p. 31), it is useful to follow the approach of Lupton (1999), navigating between two established definitions of risk. The first definition follows the scientific line of probability of a loss argument, while the second definition is socially constructed, with risk being a "product of historically, socially and politically contingent 'ways of seeing'" (Ibid. 2009, p. 31). Casimir also suggests acknowledging that there are objective risks which are "often mediated differentially through individual, cultural and historical processes" (Ibid. 2009, p. 31, quoting Lupton 1999, p. 35). Different than in mainstream climate change adaptation literature, risk is not a universal thing in time and space, but a concept that is influenced by individual social status (e.g., age, gender, class, occupation) as well as by natural and cultural surroundings. There are societies that do not use a risk-like concept (Casimir 2009); for example, studies indicate that drought has been defined as a disaster by external actors, while local communities have categorized the same dry conditions as rather normal, and not dangerous, because they rely on other indicators and modes of valuation (e.g., Meze-Hausken 2004; Müller-Mahn and Everts 2013).

Typical climate-related risks (e.g., losing one's home through flooding, losing a harvest through drought, or suffering from a higher probability of getting infected with malaria) are just one side of the story. These losses harm basic human needs, such as food, shelter, health, and security, which are relevant to all human beings. Disaster reduction programs are planned in a way to reduce these official risks. Though the distinction between *official* and *unofficial risk* is not established in the climate change adaptation literature, it is helpful in understanding people's ways of prioritizing risk, assigning blame, and responding to threats (Eguavoen 2013). Official risk, to our understanding, is the consideration of general threats to human well-being. Official risk is formally recognized by governments and aid agencies and is a legitimate object of policy documents.

Unofficial risk, on the other hand, depends highly on the social and cultural context. Unofficial risk means awareness and fear from causal relations that are not scientific, or at least not easy to grasp empirically, such as a fear of the supernatural. It can manifest itself in a fear of sorcery, of the power of ancestral spirits, or of punishment from the Almighty. Belief and superstition are at the heart of unofficial risk and may manifest in different domains of the same society, such as in (re) production, health, kinship, politics, or religion. They are often connected to the immediate social environment: the danger of being betrayed or disregarded or the fear from greed, jealousy, malevolence, and even sorcery from somebody within the family or community. Unofficial risk is usually neglected by scientists, governments, and aid agencies. It is, however, of great relevance to many people in Africa (and beyond), driving their decisions and activities, because it contributes to the cognitive process of constructing meaning around observations of social and environmental change. Moral transgression as a causal variable in cause-and-effect relationships is often reported under conditions of social and economic transformation which bear an uncertainty about the near future.

The analysis of *cultural weather discourses* worldwide has shown that "[a]ccounts of cultural or moral change are often associated with narratives of changing climate and vice versa [...] Weather can be called or diverted by human action, and atmospheric conditions have frequently been explained with reference to a religious context" (Strauss and Orlove 2003, p. 4, for a systematic review of the studies, see Peterson and Broad 2009). There are numerous manifestations of the idea of weather manipulation, rituals for rainmaking and rain-breaking with specialized utensils and offices, oral traditions (proverbs, songs, mythology) that reveal how power is structured within society, as well as scientific technologies for weather manipulations, such as cloud-seeding. The basic idea of this exploration is to understand the linkages between human perception, behavior, and weather phenomena. For example, anthropologist van Beek explores whether environmental problems have repercussions on storytelling and visions of the future. According to him, the relevance of analyzing tales and myths lies in the fact that any presumed past implies a projected future, both hinging on a perceived present. He states that, "whatever the strange forms and curious tales of myths and legends, the topics always address the worries, concerns and crucial dilemmas of the people, including ecological headaches. Often, these are social in kind and political in consequence" (van Beek 2000, p. 30).

Based on evidence from the South African Lovedu society in the 1940s, Douglas and Wildavsky argue that "for a total disaster, responsibility is located at the top. The geographic and social range of the natural disaster indicates the place in the political hierarchy where the likely transgression has taken place" (1983, p. 39). One could simplify this argument by saying that *different scales of blame* exist and that people tend to ascribe responsibility to the scale where the unwanted condition occurs or to the scale where they believe it occurs. Thus, if a harvest fails and farmers do not receive information about similar failures of harvests in other countries, they receive only a knowledge fragment and, thus, tend to perceive failure as a local problem. As a consequence, farmers assign responsibility and blame to the local and sub-local scales (individuals, their community, and their local authorities) instead of ranking it on a larger scale (e.g., a West African region which is affected by climate variability) with other frames of responsibility. Scientific smattering about global environmental change and uncertainty leads to a fallback on familiar models of blame as a local problem (at the local scale). At times, themes of international politics merge in mental models depending on the exposure of farmers to research, global news, and national political interest. Again, these examples can be understood as outcomes of sensemaking:

> Senegalese farmers identified two main causes for climatic changes; resource (mis)management and meteorology, though "a few participants – those who had taken part in our [...] field research on carbon sequestration – cited CO2 and other greenhouse gases as drivers of climate change. The most [...] controversial factor discussed was [...] a cloud seeding device [...] Although none of the discussants had seen the device, the 'machine' was (wrongly) believed to be responsible for the 2005 rains throughout the entire country" (Tschakert 2007, p. 390).

While weather discourses during the 1990s in Tanzania elucidated moral transgression in the community, the loss of the traditional institutions, and the El Nino for the negative changes in rainfall, the discourse in 2004 was that George W. Bush was personally responsible for the hot and dry weather: "it's all because of that Bush and his [Iraq] war. We don't know why God is bringing *us* these problems for *his* mistakes" (farmer quoted by Sheridan 2012, p. 233).

Late Ethiopian Prime Minister Meles Zenawie explained on several occasions that the industrial pollution and CO2 emissions were responsible for the devastating droughts in Ethiopia during the 1980s. The debate on climate change adds another facet to the older debate on the origins of poverty in Africa. The old call for fairness and compensation gets rephrased during international climate negotiations: "we are prepared to walk out of any negotiations that that threaten to be another rape of our continent" (Meles quoted in Eguavoen and zur Heide 2012, p. 107f).

The vulnerability to climate change discourse is wholeheartedly embraced by the government of Tanzania as a welcoming scapegoat to explain the marginalized situation of the Maasai population. The same government recently evicted thousands of pastoralists of their land, and excluded them from their most vital natural resources, to sell the land to a royal Arab family for game hunting purposes (field research by Sara de Wit).

One debate that materializes into the studies on climate change in Africa, if done by social anthropologists or historians, is the well-documented *connection between rain and politics*. "Rain is a political process across much of sub-Saharan Africa [. . .] the authority of leaders in colonial Africa rested, in part, on the performance of rituals to bring rain and ensure the fertility of both people and land [. . .] secular notions of power, legitimacy, and authority now co-exist and hybridize with discourses about rain, morality, and metaphysics [. . .] the politics of rain are deeply interwoven with the politics of kinship, class, ethnicity and gender [. . .implying] the notion that political order brings ecological order in the form of reliable rain – but that conflict brings drought – functions as the rhythm of political improvisation" (Sheridan 2012, p. 231). There are a number of historical examples for the rain-politics link (for a brief review, see Sanders 2003), as well as numerous empirical examples of our times:

Climate change in Mozambique is understood as the result of "lack of rain ceremonies or improper rain ceremonies" (Shaffer and Naiene 2011, p. 233). The background of this lack is political. During the civil war, the government banned traditional rituals, some of the local authorities and many cattle died during the conflict, herds could not be replaced easily after the civil war – both preventing the conduct of the rituals that use animal sacrifices. In the discourse and thus the mental models, post-war disorder was correlated to negative changes in the weather (Shaffer and Naiene 2011).

The Maasai pastoralists in Northern Tanzania perceive changing patterns of rain to have coincided with the introduction of Christianity. With an explicit ban on visiting the traditional spiritual leader, the church contributed to the degrading power of the so-called oloiboni. Instead of praying under the tree, the collective rain ritual nowadays largely takes place in churches, where the power of establishing the connection between God and His people – through mediating rain – lies in the hands of the pastor (field research by Sara de Wit).

Other trajectories of blame can be revealed when investigating *translation practices of climate change discourses* from the global to the local scale and what happens at the intersection of their discursive encounters. Often, climate change is not perceived as a global phenomenon with remote causes and diverse manifestations worldwide, but as a phenomenon localized in cause and effect. However, these perceptions might be altered when *the idea of climate change travels* and fuses in the encounters between this externally imposed idea and local explanatory regimes about a changing climate. In order to explore this "multilevel connection between global and local phenomena," enticed by global environmental discourses, Adger et al. fruitfully employ a *political ecology* approach (Adger et al. 2001). They demonstrate how political ecology forms a fertile analytical lens to trace the *genealogy of environmental narratives*, which identify the power relationships that are supported by such narratives, and the policy prescriptions that emanate from them.

Outlook

In a recent critique of the adaptation concept in the climate change literature, Bassett and Fogelman come to conclude that there is a "strong sense of déjà vu in reading the IPCC reports and climate change journal articles" (Bassett and Fogelman 2013, p. 51). Their content analysis shows that 70 % of the literature under review deems climate impacts as the major source of peoples' vulnerability (Bassett and Fogelman 2013, p. 42). This conceptualization of adaptation bears many resemblances with earlier arguments of the hazard school of thought, which sees vulnerability as the outcome of exposure, sensitivity, and mitigating responses (Bassett and Fogelman 2013, p. 51). With this chapter, we intended to underline why the inherent *climate determinism* (Hulme 2011) in the climate change adaptation literature is highly problematic and why the political needs to be brought back into the discussion of climate change.

First, academic explanations based on political perspectives are still marginalized in the major adaptation discourses (as the social science disciplines are in climate change research), with the effect that structural causes that make people vulnerable in the first place (and that we have discussed under the political agendas) are overlooked. Donor and government interventions, therefore, often remain technocratic, as they do not challenge and address the social and economic factors that lead to peoples' vulnerability. These politically conservative approaches do not challenge the status quo, but tend to fix the deficiencies at the surface (Bassett and Fogelman 2013, pp. 44–46).

Second, in a similar vein, with the emergence of the *adaptation imperative* (a normative imperative invoking the plight of the most vulnerable), there is a strong need for analyses of the discursive framings of adaptation and what they reveal about power relationships (Wisner et al. 2012). Through increased funding possibilities, adaptation programs could share the same characteristics as James Ferguson's *anti-politics machine of development* (Ferguson 1994). Studies need to include an analytical separation of *knowledge about climate change* (mental models of local climate change) on one hand and *knowledge about adaptation resources* (funding, programs, and career opportunities) on the other to get a clearer picture of the dynamics within the CCA arenas.

Third, and closely linked to what has been written above, actors respond to climate change impacts, as well as to the *idea of adaption*, as articulated by science, politicians, the media, and the donor community (Head 2010). Answers to the "adaptation to what and why" question (Pittock and Jones 2000) will have to take into account the fact that actors act upon the scripts provided by potential supporters (Watts 2001; Rottenburg 2009). Adaptation to climate change is more than what the IPCC envisions, and therefore, "adaptation cannot be adequately explained as a response to climatic stimuli, but [. . .] it also involves reactions to prevalent ideas and the incentives of new funds" (Weisser et al. 2013, p. 117). The authors also point out that "Focusing on various translations of the travelling adaptation idea helps to reveal the politics involved in North-South cooperation and thus open up a public space for negotiation" (Ibid. 2013, p. 117).

Fourth, due to the fact that climate funds channeled to the Global South might surpass official development assistance (ODA) in the future, Ireland and McKinnon argue that not only should adaptation research focus on vulnerable communities but also on those "places where policies are made, funding decisions taken, or new themes and approaches circulated amongst development professionals" (Ireland and McKinnon 2013, p. 2). Thus, our research also needs some new agenda-setting including perceptions, priorities, and social dynamics in African research centers, in environmental ministries and agencies, in civil society movements, and in the business context, as well as research about African COP delegations.

Fifth, while the previous argument proposes a new ontology for adaptation, we stipulate that *epistemological reflections about adaptation* similarly deserve attention, as they reveal how different actors may assemble around the adaptation paradigm in the CCA arenas. Adaptation means different things to different people (Head 2010; Bassett and Fogelman 2013), for adaptation activities are embedded in particular socio-cultural contexts (O'Riordan and Jordan 1999; Nelson et al. 2009; O'Brien 2009). As Rottenburg has shown for North–South cooperation, in general, project parties are united under a *common meta-code* (Rottenburg 2005), and in this way, donors and recipients act upon the common objective of adaptation to climate change. While in their interactions they refer to adaptation as a common meta-code, the distinct cultural codes of each of the partners differ profoundly. Program and project activities might be labeled as adaptation to climate change; however, the rational to do so might differ starkly. As Weisser et al. (2013, p. 117) put it: "Adaptations observed in places different from those where the idea of adaptation is produced are modifications of the latter, and can be considered as results of *translation processes*. Ontological and epistemological reflections [. . .] are opening up new perspectives for future research".

Finally, to better highlight the inherent political dimensions and social dynamics of adaptation, as well as the *emic perspectives* on change, risk, and adaptation, we believe that it is very helpful to look beyond the climate change adaptation context. Multidisciplinary research could, more often, build on social environmental sciences and their theoretical contributions. We hope that the suggested concepts and terminology help to support future research in Africa and elsewhere in this regard.

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Pricing Innovation in Climate Change Adaptation (CCA): Hedonic Valuation of R&D That Can Favor CCA

Johann Jacob, Jessica Bouchard, Moktar Lamari, and Éva Anstett

Contents

Abstract

Ever since climate change became a collective concern, governments have diversified incentives encouraging firms to mitigate climate change by investing in new technology development. However, many decision makers still question their value and wonder what determines climate change adaptation (CCA) at the firm level. This chapter deals with two questions: What makes some firms more committed to CCA than others? To what extent do R&D-active firms invest in new technologies required by CCA? Data were gathered using a 2012–2013 online survey conducted among 255 R&D-active firms in Canada (Quebec). Our dependent variable measures firm investment in technology acquisition, and independent variables are related to firms' CCA effort and to their context. Our results suggest that CCA-active firms are (i) highly innovative, (ii) intensive in R&D, (iii) investors in physical capital, and (iv) open to external knowledge.

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The model developed suggests that firms invest, on average, $5,358 a year to acquire new technologies related to climate change adaptation for each level of impact on CCA (10 levels used in our research). Our results are groundbreaking in terms of pricing the specific R&D impacts on CCA at the firm level. They indicate that the activities of research centers like technology transfer organizations make a difference in terms of CCA, especially to enable actions in the private sector. Our findings also help the public sector to improve its actions targeting CCA (e.g., tax credit or grants for firms acting in CCA).

Keywords
Climate change adaptation • Public-private R&D collaborations • Technology transfer organizations • Cost-benefit analysis

Introduction

Existing productive processes used by industries and firms have major and increasing impacts on climate change. On this subject, the works of Stern (2006) are eloquent, if not alarming. In their pursuit of productivity and optimization of profits, firms generate negative externalities on several fronts (i.e., some results affecting not only the firm but some other parts of the society): air pollution, fumes from harmful waste, overexploitation of fossil fuel resources, greenhouse gas emissions, etc. and the ensuing consequences for climate change (Zarka 2010). At the same time, to assist firms in innovating and adopting technologies that pollute less and are more adapted to the risks of climate change, several government policies and measures have been implemented, particularly in the last decade, to assist and encourage firms in reconciling the seemingly irreconcilable, namely, the requirements of profitability versus the requirements of climate change adaptation (Gupta et al. 2007; Braüninger et al. 2011). In Canada, these efforts have notably expanded in the last 6 years through, for instance, public subsidies that were given to some research centers: technology transfer organizations (TTOs). These organizations (which are research centers specially created to help transfer knowledge from universities and scientific literature to firms) aim to help firms which are seeking to innovate to reconcile their performance objectives with those of adapting to climate change. More generally, these organizations create, acquire, adapt, and transfer new technologies for firms wanting to innovate and improve their competitiveness, not only in local markets but also internationally. All evidence suggests that an apparent evolution is taking place, pressuring firms to consider the effects of global warming and invest in "green" technologies that are more adapted to the specificities of their local environment. Everything seems to indicate that these firms are part of a movement favoring the global environment, like an ecosystem transcending time, space, and the wealth of nations (Gupta 2005).

The complexity of climate change phenomena requires expertise and technologies that firms cannot always acquire alone without any public assistance (Osberghaus et al. 2010). The issues raised by climate change require resilience and a proactive approach that take into account intra- and intergenerational interests, in keeping with the aspirations of the Brundtland Report on sustainable development of the World Commission on Environment and Development in 1987, taken up again by the United Nations at the Rio Conference 5 years later (Zarka 2010).

Public funding of research and development aims at correcting certain market failures related to innovation by encouraging private-sector actors to produce technological innovations enabling the reduction of greenhouse gas emissions or by providing adaptation options. At the same time, recent years have witnessed the appearance of many writings on the relationships linking the necessity of climate change mitigation and the progressive commitments of firms to invest in the acquisition of new technologies that can help them do better in their markets but with productive procedures and processes that are less prejudicial to climate change (Howarth 2003). However, these writings do not help to understand why only some firms invest in the acquisition of new technologies that are compatible with concern for climate change mitigation and CCA. They remain dominated by descriptive and reflective analyses (Paehlke 2014). Not much is yet known about these attributes and, quantitatively, even less about the net economic value attributed by firms to the beneficial spin-offs of climate change adaptation within firms. To our knowledge, no study has valuated the use of grants as a mechanism for stimulating technology transfer in CCA specifically (Intergovernmental Panel on Climate Change 2014a).

The investigations presented in this text advance knowledge by offering empirical evidence concerning the behavior of firms receiving support from TTOs in the area of CCA. In concrete terms, this chapter highlights the determinants that influence certain firms to be more committed than others to climate change adaptation thanks to their effort to acquire new technologies required in CCA. This chapter provides answers to two key questions within the Canadian context. The first question deals with the principal attributes characterizing firms that collaborate with TTOs with regard to climate change adaptation. The second question deals with the economic value of the demands of climate change adaptation according to these R&D-intensive firms.

The remainder of the text has been divided into four parts. The first part puts into perspective the conceptual and theoretical issues linked to the challenges of climate change within the context of industrial activities, in general, and of firms, in particular. The second part presents the empirical approach and data used to respond to the questions asked. The third part deals with the results and interprets their scope and implication for public policies targeting climate change adaptation in the context of firms and industrial activities. The conclusion takes stock of the results and introduces perspectives for action, not only for the public decision makers concerned but also for future empirical research dealing with the same subject.

Theoretical Background

The issue of climate change encompasses several aspects that have raised controversy and differences of opinion in scientific writings. These differences can be explained in large part because the evidences produced cannot be compared regarding the validity of the estimates and hypothesis presented. The estimated costs associated with respect to reducing greenhouse gases are an example, and the economic forecasts concerning the possible expected damages also differ, if the present emission rates are maintained. The recognition of climate change as a significant global challenge originated in the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. Since then, global negotiations on this issue have tended to emphasize minimizing the costs related to reducing greenhouse gas emissions. The preservation of ecosystems and the population's adaptation to these changes have been dealt with less (Gupta 2005).

Obviously, all societies are affected by climate change and must face the issue of mitigating its effects and adapting to it. In recent years, the World Bank and the Intergovernmental Panel on Climate Change (IPCC) have published reports exposing the urgency for all states to establish strategies to control climate change. Whereas climate change mitigation programs have tended to have a global focus, adaptation programs have had a regional or local dimension. The IPCC defines adaptation to climate change as an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation" (Intergovernmental Panel on Climate Change 2014a). Climate change mitigation is stated as "an anthropogenic intervention to reduce pressure on the climate system." It includes strategies to reduce the sources and emissions of greenhouse gases and enhance the sinks of greenhouse gases (Intergovernmental Panel on Climate Change 2014a).

Unquestionably, the strategies implemented to respond to the requirements of climate change involve costs and benefits that are distributed asymmetrically through time and generations. The extent of future greenhouse gas emissions depends on the paths of economic, demographic, technological, and energy development of each nation (Pielke 2007; Hallegate et al. 2011). These parameters are therefore complex and linked to the uniqueness of states and regions. In addition, significant uncertainties surround the estimated long-term impacts of climate instability (Intergovernmental Panel on Climate Change 2013) that are, in turn, subject to uncertainty regarding the future paths of socioeconomic development, climate policies to be implemented in the future (Intergovernmental Panel on Climate Change 2013), and the response and adaptation of ecosystems (Intergovernmental Panel on Climate Change 2014b). For example, based on a literature review, the IPCC estimated that the present level of greenhouse gas emissions could cost about 1.5–2 % of the global economic output, with greater impact on developing countries. However, a consensus about these estimates does not exist in the literature, and they differ according to the disciplines and researchers (Howarth 2003). Stern (2006) estimates that these costs would be in the order of 5–20 % in terms of GDP per state. The most recent estimates from the World Bank place climate change adaptation costs at between $70 billion and more than $100 billion annually by 2050 (World Bank 2010).

Climate change has undeniable economic impacts. From an economic standpoint, political entities and socioeconomic organizations combine their climate change efforts by introducing programs that are in the interests of their population. Climate change is indivisible and cannot be measured with precision. This leads firms to adjust their efforts between adaptation and mitigation measures (Maybee et al. 2012).

Nevertheless, there is a consensus surrounding the adaptation measures taken during the last century that turned out to be insufficient. Autonomous actions can be undertaken by the civil society, in particular, but also by private enterprise. In this sense, private actors are expected to take autonomous adaptation measures based on their interests and whose anticipated benefits will be greater than the costs (Maybee et al. 2012). Nonetheless, several experts highlight the fact that autonomous adaptation initiatives can fail for several reasons, in particular, because the agents affected by climate change do not always have the capacities, resources, and other factors necessary to undertake such measures. Moreover, many of these actions cost more than the estimated benefits (Eisenack 2013; Hughes and Chaudhry 2011). Finally, in certain cases, the adoption of a socially desirable behavior (specifically an adaptation action) does not appear to be profitable to a private agent, constituting market weakness situations. For example, negative externalities may result from the adaptation actions taken by certain agents leading to even more harm to third parties (Goulden et al. 2009). As well, a moral hazard situation occurs when a climatic risk is transferred to the population, in particular, through an insurance mechanism or through post-disaster aid offered by the state (Laffont 1995).

Within this framework, some states and international government organizations have recognized the necessity to manage this question and to develop public policies of adaptation and reduction of the effects of climate change. Governments are mainly concerned with formulating adaptation policies and strategies for climate change, as well as developing a governance structure to ensure their implementation. As this policy development process is relatively recent, studies have looked into climate change adaptation measures by setting out their limitations. They have dealt with government failures, in particular, the lack of political and conscientious leadership with regard to needs, as well as the weak financial resources available for these initiatives. In addition, there is the presence of a lack of political commitment, inadequate interstate cooperation, an insufficient level of government expertise (Clar et al. 2013), and limited adaptation capacities, especially in developing countries or in countries with limited access to capital (Brooks et al. 2005). Also, decision makers can occasionally set barriers through their cognitive and behavioral biases (Podsakoff et al. 1990).

The literature includes a large number of studies analyzing policies and interstate cooperation with regard to climate change, but only a minority take an interest in non-state actors and their climate change adaptation and mitigation initiatives. Even so, recent research in this area has permitted to illustrate the importance of accompanying national and supranational CCA measures with additional policies, enabling the mobilization of other actors, such as firms, business associations, and local organizations (Hamit-Haggar 2012; Craft et al. 2013).

Burch et al. (2013) examined this question and brought to light the importance of governments resorting to innovative approaches to encourage industry and private enterprise to take action in this area. By studying Canadian firms involved in R&D having a positive impact on climate change adaptation, they advanced the idea that firms assume an innovative, creative, and dynamic character (Burch et al. 2013, p. 822). They also emphasize that the issue of climate change must be handled by different governance levels; measures must be implemented at the local, regional, national, and international levels.

Several governance experts acknowledge that the rigid, centralized state method cannot respond to all public-policy issues, and the climate change question requires a multi-sectoral, multilevel governance model (Burch et al. 2013, p. 822). This allows actors involved in R&D and CCA to increase their ability to act and make their initiatives more effective while, at the same time, fostering the horizontal and vertical transfer of technologies, knowledge, and information among them (De Coninck et al. 2008).

There is also a consensus that initiatives in the fight against global and national climate change must be accompanied by local action (Craft et al. 2013). As stated above, this issue has major economic impacts that are already being felt. To limit the negative externalities of climate change adaptation and mitigation, measures must be taken to limit the damage and ensure longer-term economic growth. So, it is essential that governments take into account that effective parallel mitigation factors must also be implemented in order to enable climate change adaptation (Paehlke 2014).

In the Canadian context, climate change adaptation and mitigation have followed a tortuous path. A clear example is the Canadian ratification of the Kyoto Protocol and the subsequent withdrawal of approval. In 2007, the Canadian federal government acknowledged that meeting the objectives set by Kyoto would be unachievable and introduced new greenhouse gas reduction targets in a document entitled Turning the Corner. This new policy involves reducing GHG emissions by 20 % by the year 2020, based on 2006 levels (Hughes and Chaudhry 2011). Industry also has a role to play in this issue. In 2007, the industrial sector was responsible for 32 % of GHG emissions in Canada (Hamit-Haggar 2012). Overall, GHG emissions increased by 16.9 % in Canada between 1990 and 2009, representing 22.9 % over its commitments made within the framework of the Kyoto Protocol. In 2011 and 2012, Canada formally withdrew from Kyoto and drastically reduced the size of its environment ministry. The significance of these developments is that they increase the importance of developing innovative local actions and the development of networks devoted to the strategic sharing of information permitting state and private actors working for climate change mitigation and adaptation to work together (Burch et al. 2013).

Thus, Canadian federal and provincial governments resort to a system of governance that is more and more widespread in industrialized countries with regard to climate change. It involves a partnership between the public and private sectors, including the participation of several actors: government agencies and organizations and large, small, and medium-sized businesses. In this chapter, we are targeting this type of partnership between firms and technology transfer organizations (TTOs) that are funded in part by the federal and Quebec governments. Technology transfer organizations are defined as entities acting as catalysts between government and academic research teams, on one hand, and industries, on the other (Grosse 1996, p. 782). Technology transfer is defined as “the process of transferring skills, knowledge, technologies, methods of manufacturing, samples of manufacturing and facilities among governments or universities and other institutions to ensure that scientific and technological developments are accessible to a wider range of users who can then further develop and exploit the technology into new products, processes, applications, materials, or services. It is closely related to knowledge transfer. Horizontal Transfer is the movement of technologies from one area to another. Vertical Transfer is when technologies are moved from applied research centers to research and development departments” (Grosse 1996, p. 782).

The TTOs have the characteristic of assisting firms in R&D and in adopting technologies that are more adapted to the risks of climate change. Their large network is made up of public administrations but, even more so, of small- and medium-sized private-sector firms. There is evidence in the literature suggesting that, despite their size and limited resources, small and medium-sized businesses are able to have significant positive impact on climate change adaptation and mitigation. This can be explained by the fact that, compared to large firms, smaller firms have a closer relationship with their community and their workers and are less subject to pressure from shareholders to maximize profits (Burch et al. 2013, p. 826). In addition, by taking into account the fact that a multi-sectoral, multilevel governance favors the development of climate change adaptation measures, TTOs can play a key role in capitalizing the strengths of the actors in their climate change adaptation efforts, while maximizing their innovation potential and establishing channels of communication among these firms.

Furthermore, to respond to the uncertainty surrounding the question of climate change, several economists and economic actors tackle the problem in terms of cost-benefit analysis (Maddison 1995; Tebaldi et al. 2005). Such an approach evokes the rationality of the economic optimization of dividends anticipated by the actors. This approach consists in taking into account the costs and benefits that would result from a project, in discounting them, then in calculating the real net value. The cost-benefit analysis thus permits to demonstrate the practical implications of a decision from a welfare standpoint (Townley 1998). The cost-benefit method is also thoroughly documented in the literature on R&D. It has been retained for this analysis.

In cost-benefit analysis, the choice of the discount rate has a significant impact on the net present value and is the subject of debate in the literature. The cost-benefit analysis applied to climate change is linked to this debate since it is spread over a long time horizon (Baum 2009; Heal 2009). As a result, choosing a higher discount rate will tend to dissuade taking mitigation measures because the related costs will be higher than the expected benefits to be reaped further along in the future. Conversely, choosing a lower discount rate will permit attributing a higher value on anticipated future benefits and thus gives more importance to decision making to control climate change (Hof et al. 2010). In addition, as this type of analysis focuses on impacts affecting several generations, ethical and moral questions come into play in choosing the discount rate (Stern 2006). It emerges that there is no consensus among experts with respect to this question. In the latest report of the IPCC, it is stated that the rates used vary between 0.1 % and 2.5 % for CCA projects (Intergovernmental Panel on Climate Change (2014a). The Stern Report (2006) exposed the seriousness of the harm to the global economy as a result of climate change, a negative externality whose extent should increase in the future. Nonetheless, this report was the subject of criticism since the discount rate used by the author was 0.1 % which, according to some, resulted in an overestimation of the future impacts linked to climate change and an underestimation of the extent of the costs to be assumed to contain their effects (Dietz et al. 2007). And so, the principal reason why climate change damage estimates in the Stern Report are high is the low discount rate.

Furthermore, to include all impacts in the cost-benefit analysis, economists have developed methods to assign a monetary value to intangible impacts. In fact, certain impacts to be considered in public projects are not exchanged on the market and do not have an assigned monetary value. To assign a value to this type of impact, innovative methods have been developed for this purpose. The most widespread are contingent valuation and hedonic prices.

Method

This analysis was conducted by the *Centre de recherche et d'expertise en évaluation* (CREXE) within the framework of a mandate for the *Ministère de l'Économie*, *des Innovations et des Exportations du Québec*, Canada. This mandate consisted in carrying out a cost-benefit analysis involving the study of 41 technology transfer organizations (TTOs), three of which are independent and 38 of which are members of a vast regional network. These organizations offer innovation services for local firms, specifically small- and medium-sized businesses, in the province. Their research activities are focused on applied and adapted research for direct use by their partners of the private sector; consequently, TTOs are closely in touch with firms' needs, whereas other research centers undertake more fundamental or basic research which is not directly applicable for the private sector. This policy is an example of public-sector intervention created to encourage innovation in the private sector in order for the state's grants to create leverage to increase private investment in R&D.

The data presented are from several sources and databases which can be explained because the costs and benefits studied are felt by different actors, including government agencies, firms, and TTOs. The data relating to impacts concerning governments and public organizations are from internal documents, official reports, and directed and semi-directed interviews carried out with representatives of these organizations. The internal data concerning the three Quebec TTOs were gathered from financial documents, annual reports, and strategic plans supplied by the three firms.

Two types of surveys were conducted between October 2012 and March 2013 among 1,500 firms and public organizations involved in R&D in Canada (Quebec) and working in collaboration with the TTOs studied. First, a telephone survey was carried out by an external firm, with a response rate of 65 %. Then, an electronic survey was carried out. The data were collected using the Survey Gizmo platform; the average response rate for this survey was 25 %.

These two surveys enabled the estimation of costs and benefits, as well as the impacts taken into account in the analysis. The questions were formulated in order to obtain continuous numerical data. For the variables that were more difficult to measure, the questions provided possible responses from 0 to 10 in order to allow respondents to estimate the extent of the impacts studied.

The collaboration with the TTO of the firms included in the sample was therefore analyzed to assess whether their collaboration had an impact on investments targeting CCA. The questions asked to respondents within the framework of the surveys focused mainly on assessing the impact of their firm's collaboration with the TTO: on climate change adaptation, reducing greenhouse gas emissions, the environment, and sustainable development. The sample included 255 firms that completed the survey and offered valid responses to the questions. A descriptive statistical analysis was then carried out using all these data with the help of SPSS software. These results are presented in the following section.

Moreover, to determine the estimated monetary value of the public expenditures leading to the innovations linked to CCA, the hedonic price method was used, which will be described in the next section. This economic method helps to estimate the value of intangible elements, in our case the value of firms' actions in CCA. For the purposes of assigning a value to these intangible attributes, correlation and regression analyses were produced with SPSS. The dependent variable of the multivariate regression that is presented in the following section is the total amount of the firm's contracts with the TTO for 1 year (continuous variable), and the independent variable that interests us is the impact of the firm's collaboration with the TTO on climate change adaptation (the values vary from 0, if the firm perceives no impact, to 10, if the firm perceives a major impact). Two control variables were then introduced into the model. First, as stated in the literature, R&D-intensive firms are characterized by a large workforce devoted to R&D (Grosse 1996). To cover this aspect, we added the variable of the number of staff members allocated to R&D in the firm (continuous variable). We then added the variable of innovation in terms of organizational processes and marketing activities (the values vary from 0, if the firm perceives no impact, to 1, if the firm perceives a major impact). We also introduced other control variables measuring the duration of collaboration with TTOs (number of years) and technological services (training, technological counseling, testing products, etc.), specified as a binomial variable (1 = yes, 0 = no).

Results

The findings of this study will be presented in four steps. We first present the sample characteristics and the descriptive analysis, then the statistical analysis, the hedonic evaluation, and, finally, an ordinary linear regression (OLR) explaining the determinant of investment in collaboration with TTOs.

Descriptive Analysis

To understand further the main attributes of Quebec firms collaborating with TTOs on R&D related to CCA, a characterization of Quebec firms producing impacts on CCA has been produced.

As presented in Table 1, the sample is composed of 255 Quebec firms collaborating with TTOs on R&D. The respondents are divided into two categories: those who perceived an impact of their collaboration with the TTO on CCA and those who did not. 31 respondents perceived impacts of their collaboration on CCA, which represents 12.5 % of this sample. These 31 firms and organizations are involved in the following sectors: public administration (10 %), primary sector (10 %), secondary sector (45 %), and tertiary sector (45 %).

In contrast, 224 respondents did not see impacts of their collaboration with the TTO on CCA. This subsample is composed of similar proportions of public administration (11 %) and firms working in the primary (12 %), secondary (42 %), and tertiary sectors (46 %).

Table 2 presents other attributes of firms investing in R&D impacting on CCA. These firms employ an average of 1,028 employees, and their mean annual earnings total $173 million. The mean impact of the collaboration with the TTO is estimated at $183,662 by the respondents, and the contract amount with the TTO totals an average of $29,358 annually. In contrast, the respondents who do not see impacts of the collaboration with the TTO on CCA present a lower mean number of employees (596) but higher mean annual earnings ($81.3 M). However, these firms have a mean annual contract amount of $16,676 with the TTO, which is lower compared to the firms perceiving impacts on CCA.

Chi-Squared Test and T-Test

As presented in Table 3, the collaboration between the firms investing in R&D impacting on CCA (n = 31) and the TTO led to investments in internal R&D (71 %), external R&D (70 %), access to tax credit for R&D (70 %), and acquisition of machines, equipment, and software (57 %). Furthermore, this collaboration leads

Table 1 Characterization of Quebec firms producing impacts on CCA

Question : Please estimate the impact of your collaboration with the TTO on CCA (on a scale from 0 to 10, 0 representing no impact and 10, a maximal impact)	Impact on CCA >1 ($n = 31$)	Impact on CCA = 0 ($n = 224$)
	n (%)	n (%)
Sector		
Public services	3/29 (10 %)	23/204 (11 %)
Primary sector	3/29 (10 %)	25/204 (12 %)
Secondary sector	13/29 (45 %)	86/204 (42 %)
Tertiary sector	13/29 (45 %)	93/204 (46 %)

Table 2 Characterization of firms investing in R&D impacting on CCA

	Respondents seeing impacts of the collaboration with the TTO on CCA			Respondents not seeing impacts of the collaboration with the TTO on CCA		
	Mean (SD)	Median	n	Mean (SD)	Median	n
Number of employees of the firm	1,028 (3,390)	40	23	596 (1,814)	55	191
Earnings ($) (*annual*)	$17.3 M ($26.8 M)	$7.9 M	26	$81.3 M ($332.5 M)	$8 M	195
Profits ($) (*annual*)	$906,577 ($2.03 M)	$191,326	18	$3.9 M ($22 M)	$391, 000	143
Estimate of the impact ($) *of the collaboration with the TTO*	$183,662 ($312,643)	$50,000	19	$215,740 ($652,189)	$10,000	127
Spin-off benefits ($) *due to collaboration*	$100,834 ($248,510)	$22,843	22	$355,835 ($2.6 M)	–	177
Contract amount with the TTO (*for 1 year*)	$29,358 ($70,157)	$17,500	27	$16,676 ($31,283)	$6,644	184

to the acquisition of exterior knowledge (39 %), the hiring of specialized human resources (37 %), and other innovation-related activities. These results are statistically significant at the 5 % level (chi-square lower than 0.05).

These statistics show that firms that adopt CCA are highly innovative and more R&D-intensive, both internally and externally. Moreover, these companies make investments in capital and are more open to external skills and knowledge. This evidence suggests that TTOs can play an important role in innovation related to CCA.

However, there is no statistically significant difference regarding other parameters, such as the number of employees, the annual earnings, and profits. However, the companies that adopt CCA do not necessarily have large earnings but employ a large workforce.

Overall, it emerges that these firms present the common characteristics of employing large workforces, particularly in R&D, and of being highly innovative in their sector of activity.

Pricing CCA from Implicit Behavior

Hedonic Evaluation

To assess the value attributed by the actors doing R&D on CCA innovation, we used the hedonic pricing method. This method aims to give a monetary value to impacts, which can be broken down into price and measurable quantities. This involves deducting intangible individual preferences and behavior on the markets from other goods and services (Townley 1998). Formulating the argument

Table 3 Characterization of the sample (firms and CCA)

	Firms seeing impacts of their collaboration with the TTO on CCA ($n = 31$)	Firms not seeing impacts of their collaboration with the TTO on CCA ($n = 224$)	
	n (%)	n (%)	Chi sq
Collaboration with the TTO led to investments in			
Internal R&D in the firm or organization	20/28 (71 %)	95/209 (45 %)	0.01**
External R&D	19/27 (70 %)	55/208 (26 %)	0.000***
Acquisition of machines, equipment, and software	17/30 (57 %)	70/209 (33 %)	0.014**
Acquisition of immovable property	1/28 (4 %)	18/206 (9 %)	0.348
Acquisition of other exterior knowledge (except hiring specialized HR)	11/28 (39 %)	39/205 (19 %)	0.014**
Hiring specialized HR	11/30 (37 %)	33/209 (16 %)	0.006***
Training	14/29 (48 %)	94/209 (45 %)	0.738
Marketing activities	11/28 (39 %)	63/208 (30 %)	0.335
Other innovation-related activities	19/28 (68 %)	96/207 (46 %)	0.033**
Firm is eligible for an R&D tax credit	16/23 (70 %)	98/150 (65 %)	0.690

**$p < .05$
***$p < .01$

that the goods themselves are not useful to consumers but the attributes that compose them, Lancaster (1966) established the theoretical basis of this method. A good's overall price results from an implicit valuation of each of its attributes, and it is possible to determine a demand function for each attribute (Travers et al. 2008). This explicit identification of characteristics aims to compare goods despite their heterogeneity (Townley 1998).

Regressions

To understand further how the collaboration with a TTO leads to tangible impacts on CCA felt by companies, a regression model has been developed. The dependent variable is each firm's contract amount for one year (CA) with the TTOs. The independent variable is the impact perceived by the respondents of the collaboration on CCA; the values range from 0, if the firm sees no impact to 10, if the firm sees a major impact (Likert scale). We added several control variables to the model: the number of employees working in the R&D department of the firms, the implementation of innovative products following collaboration with the TTO, the duration of the collaboration with the TTO, and the technological services received from the TTO.

Table 4 Ordinary linear regression (OLR) explaining the determinant of investment in collaboration with TTOs

	Nonstandardized coefficients		Standardized coefficients		
	B	SE	Beta	t	Sig.
Constant	−76,979.219***	19,688.503		−3.910	0.000
Innovation	10,573.764	13,199.239	0.065	0.801	0.425
Climate change adaptation (CCA)	5,358.041**	3,637.278	0.120	2.173	0.044
Duration of the collaboration with the TTOs	5,319.612***	1,210.648	0.366	4.394	0.000
Services received from the TTOs	55,294.401***	13,135.475	0.346	4.210	0.000
Number of R&D employees (Ln)	8,368.429***	3,138.098	0.224	2.667	0.009
Number of observations	143				
R2	0.294				
P-value	0.000				
F	9.036				

Dependent variable: Total amount of contract with the TTOs
**p < .05
***p < .01

Table 4 presents an ordinary linear regression explaining the determinant of investment in collaboration with TTOs. The regression exhibits an R2 of 0.294, significant at the 1 % level (P-value = 0.000; F = 9.306) and comprises 143 observations. The results suggest that our model explains 29 % of the variation of the dependent variable (total amount of the contract with the TTOs). These feet indicators are acceptable, indicating the quality of our model specification. Of these five control variables, four regression coefficients are statistically significant, besides the constant. The CCA variable is significant at the 5 % level, and the other three control variables are significant at the 1 % level.

(1) The relationship between the total amount of the contract with the TTOs and the CCA is positive. Other things being equal, firms allocate, on average, $5,358 for each level of impacts on CCA. (2) The duration of the relationship with the TTOs is also positively associated with the dependent variable and, other things being equal, the amount of the contract increases each year, on average, by $5,320. (3) The services received from the TTOs in terms of training, technological counseling, and testing products increase, all else being equal, the value of the dependent variable by $55,294, which is very high. (4) The number of R&D employees (Ln) is also highly and positively associated with the dependent variable.

Our findings are very inspiring in terms of the amount of money firms are investing in order to acquire useful new technologies devoted to CCA. These results enhance the importance of R&D employees for innovating firms and in this case in the CCA.

Conclusion

The results of this research suggest, first of all, that Canadian TTOs can play a crucial incentive role regarding innovations related to climate change adaptation. Our study's respondents have perceived that their collaboration with a TTO generated both internal and external R&D investments while, at the same time, promoting other innovation activities.

Thus, our conclusions from the analyzed descriptive statistics are that innovative firms in the area of climate change adaptation are more R&D-active and make large investments in physical capital and specialized human resources. They are also more open to acquire external knowledge. On the other hand, contrary to our expectations, there are no significant differences with regard to the other parameters taken into account (see Table 3), such as the number of employees, the marketing activities, and annual profits.

At the same time, this research extends knowledge about the ways of assigning a monetary value to firms' R&D activities impacting on climate change adaptation. The regression model developed suggests that firms invest, on average, $5,358 a year to acquire new technologies related to climate change adaptation, for each level of impact on CCA.

In the light of the content of this chapter, climate change mitigation and adaptation are major economic issues whose costs and benefits are spread throughout a broad time horizon. Even if autonomous private-sector initiatives have been observed, the risks and uncertainties surrounding climate change can curb investments in this area since private firms protect themselves against large potential losses and make sure they obtain a return on their spending (Howarth 2003). Therefore, what emerges from the literature relating to climate issues is that states and public administrations must encourage climate change adaptation efforts by industry and firms and establish conditions guaranteeing their success (Paehlke 2014). To this end, the Canadian government provides financial assistance to technology transfer centers directly targeting R&D-active firms in order to reconcile their performance objectives with those of adapting to issues related to climate change.

The results of this research show that TTOs can play a key role in climate change adaptation within the framework of their collaboration with the member firms of their network. Our work demonstrates how this type of public-private partnership can lead firms to invest in CCA while still developing profitable innovations for the whole society. Our conclusions are also the same as those of writings dealing with the importance of local and regional initiatives concerning climate change. Hence, the development of policies targeting intersectoral exchanges between R&D firms committed to climate change adaptation is an option to be considered by public decision makers. This research therefore suggests the implementation of measures to strengthen private CCA initiatives in order to make them more effective, on one hand, and to make entrepreneurs aware of the crucial role they can play in reducing the risks associated with this issue, on the other. Public authorities should also consider additional incentives, perhaps in the form of tax credits or grants that would then likely stimulate private investment in CCM and CCA. In addition, public funds could also introduce services and activities fostering networking among firms involved in CCA to permit the exchange of good practices, as well as to feed and accelerate the innovation process.

Our analysis opens several possibilities for future research. First of all, the model developed in this study could be improved through the use of a greater number of variables and a larger sample. The addition of new data would thus increase the model's statistical strength and permit a deeper interpretation of the results. This exercise would also make it possible to identify other characteristics attributable to R&D-active firms committed to climate change adaptation. Moreover, other research could be conducted with regard to the intangible attributes surrounding CCA innovations. For example, access to Statistics Canada's chronological data would enable the study of the impacts of public knowledge transfer programs on R&D activities concerning climate change adaptation.

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Principles of Emissions Trading

Julien Chevallier

Contents

Abstract

International emissions trading schemes include the Kyoto Protocol and the European Union Emissions Trading Scheme. This chapter documents the main principles behind the functioning of such permits markets, which represent popular environmental regulation tools. Among other design issues, this chapter discusses the various allocation mechanisms available to the regulator. Besides, this chapter underlines the role played by intertemporal flexibility mechanisms (e.g., banking and borrowing) which allow reducing overall compliance costs. Overall, the goal of this chapter is to present in standard textbook reference terms the construction of an emissions trading program, be it at the regional,

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national, or international level. The interested reader can gain valuable insights by referring to this core text, which contains a descriptive analysis of the main provisions that need to be taken care of when creating such an environmental market.

Keywords
Emissions trading • Allocation • Banking • Borrowing • Offset

Introduction

Emissions trading, or cap-and-trade program, consists in setting a quantitative limit for the emission of a given pollutant and to let the market decide on its price. How do emissions trading schemes work in practice? This chapter aims at answering this question, by casting light on the functioning mechanisms of tradable permits markets. Such markets have been created in order to be able to trade polluted assets, as if they were standard production goods. By diminishing the circulation of pollutants, environmental benefits can be awaited from such schemes. The first issue raised by the creation of a tradable permits market is linked to the distortions which can occur as a consequence of the initial allocation. Initial allocation is the amount of pollutant that is distributed to preexisting agents to start with. Whereas Hahn (1984) contributed first to this debate by demonstrating the non-neutrality of permits allocation for an agent able to exert market power[1] in a static context and concerning the spatial exchange of permits only, this chapter explicitly addresses the critical aspect of initial permits allocation in a dynamic context and concerning intertemporal emissions trading. It is important to bear in mind indeed that a permit can be exchanged across various geographical locations (e.g., from one country to another) but also through time (e.g., one firm transfers permits to the future or from the future). These different kinds of uses of permits are called, respectively, spatial exchange and intertemporal trading.

On tradable permits markets, banking refers to the possibility for agents to save unused permits for future use, while borrowing represents the possibility to borrow permits from future allocations for use in current period. Agents are a very generic term in economics which can represent individuals (e.g., consumers), firms, or governments. In our context, agents are mostly understood here as polluting firms. By allowing agents to arbitrate between actual and expected abatement costs over specific periods, banking and borrowing permits form another dimension of flexibility where agents can trade permits not only spatially but also through time. Abatement cost represents the cost to diminish the quantity of pollution by one unit. In a continuous time model under certainty, Rubin (1996) shows that an intertemporal equilibrium exists on a permits market from the viewpoint of the

[1]For an exhaustive literature review on permits trading and market power, see Petrakis et al. (1999).

regulator and the firm and that banking and borrowing allow firms to smooth emissions. Indeed, it is the role of the government (or the environmental agency) to manage the tradable permits market, which is an artificial construction coming from environmental policy. Regulator can therefore refer to the State or the environmental agency. Under uncertainty, Schennach (2000) shows the permits price may rise at a rate less than the discount rate and new public information may cause jumps in the price and emissions paths.

Such provisions enabled agents to smooth their emissions stream and played a key role in the success[2] of the US SO_2 or Acid Rain Program. Surprisingly, the inclusion of banking and borrowing does not appear as a cornerstone of new "grand policy experiments"[3] dealing with climate change.

We bridge this gap by analyzing the various effects of banking and borrowing that need to be accounted for when designing tradable permits markets. This instrument is described indeed as a double-edged sword in the literature. On the one hand, banking provides incentives to over-comply and leads to an intertemporal reallocation of emissions so as to reach lower social damages. On the other hand, borrowing may give agents with high abatement costs an incentive to delay costly investments in clean technologies by borrowing allowances from future periods and to concentrate emissions in early periods. For example, if it is costly to diminish pollution when extracting coal, firms will pollute on a business-as-usual basis at the beginning of the scheme (by borrowing future permits), and they will wait for technological innovations to diminish their quantity of pollution in the future (and the associated use of pollutants). However, more pollution has occurred in the present time, which is not the objective of the tradable permits market. That is why the provisions on banking and borrowing need to be carefully designed. While the total allocation of permits sets the present value of discounted permits prices, we will see that other effects on the permits price may arise when introducing an intertemporal trading ratio for banked and borrowed allowances. Discounted permits prices can be defined as the total value of a permit discounted through time (by applying discounting as it would apply to any savings account for individual banks).

We therefore address the following two key questions: What are the effects of the initial allocation mechanisms in emissions trading systems? What insights can we get from the existing literature concerning the use of banking and borrowing in tradable permits markets? To detail the impacts of banking and borrowing on environmental damages will also be a priority throughout our analysis.

The remainder of the chapter is structured as follows. Section "Initial Allocation Mechanics" provides a background discussion on the initial allocation mechanics.

[2]The notion of success may be approximated by various effects (preexisting regulatory environment, technology innovation and diffusion, reduction of regulatory uncertainty, aggregate cost savings, etc.), but we will focus on the efficiency of the permits price, i.e., its ability to reflect current information on spot and future prices.

[3]This expression was coined by Stavins (1998).

Section "Banking and Borrowing Provisions" deals with banking and borrowing provisions. Section "Additional Flexibility Mechanisms" introduces additional flexibility mechanisms. Section "Conclusion" concludes.

Initial Allocation Mechanics

This section addresses allocation design issues of existing international emissions trading schemes, namely, the Kyoto Protocol and the EU ETS.

The Kyoto Protocol

The Kyoto protocol is the first of its kind at the international level to introduce carbon trading, i.e., the exchange of carbon dioxide units worldwide. The question of the Kyoto Protocol as an "unfinished business" is often evoked. Very heterogenous sectors were included under the same regulation, which could be detrimental to find the right method to allocate permits depending on price elasticities between sectors.

Since there exists no historical data for carbon emission reduction cost, it may prove particularly difficult to induce a cost-effective allocation of the initial quotas to participating countries. In the context of the Kyoto Protocol, the case of countries supplied with allocations in excess of their actual needs has been coined as *hot air* in the literature.[4] The distribution of a large number of permits to Former Soviet Union (FSU) and Eastern Europe countries (Russia, the Ukraine forming two thirds) may be seen indeed as an imperfection of the Kyoto Protocol, as those countries were given generous allocations to foster agreement during the first phase (2008–2012). Market power concerns arise as industrial firms may benefit from the gap between their initial permits allocation (based on 1990 production levels) and their real emission needs in 2008 (after a period of recession), and the use of these permits surpluses remains unclear.

This situation emerged as a conflict between the internal and the external consistency of the permits market:

- The *internal* consistency refers to the situation where agents freely receive or bid for permits according to their real needs. The regulator may be interested however in distributing more permits to a country than strictly needed (according to business-as-usual emissions or a benchmark for instance) in order to ensure participation to the permits market.[5] As a consequence, one agent may achieve a dominant position which in turns threatens the efficiency of the permits market itself.

[4]See Baron (1999), Burniaux (1999), Bernard et al. (2003), Bohringer et al. (2006), Holtsmark (2003).

[5]Such negotiation with Russia was determinant for the Kyoto Protocol to enter into force on February 16, 2005.

- The *external* consistency of the permits market is linked to the broader debate of climate change as the purchase of a "global public good."[6] This altruistic view embodies the notions of "burden sharing" or "common but differentiated responsibilities"[7] attached to the Kyoto Protocol, whereby developed countries agree to spend a higher income share on fighting climate change than developing countries.[8]

Those conflicting views undermine the negotiation of the cap, which is fixed at a suboptimal level compared to what would be needed to minimize the total damage to the environment. The cap can be defined as the overall quantitative limit of pollutants that can be emitted. The regulator sets the cap, and the market defines the price of the permit. Greenhouse gas (GHG) emission targets under the Kyoto Protocol represent a mere 5 % reduction below 1990 levels. Now if early movers like EU countries are willing to ratchet down the cap, little progress can be achieved without luring in major players like the USA, India, and China. Thus, many difficulties arise to pierce the "veil of uncertainty" around international negotiation.[9]

The fact that the creation of a permits market gives some countries the opportunity to draw a financial advantage without a direct environmental gain (i.e., in the absence of effective emissions abatement) may be puzzling. Yet as stated by Maeda (2003),[10] "[this debate] seems misguided because it focuses on the political importance of the issue, rather than addressing it from an economic perspective."

Overall, the hypothesis that generous allocations that broaden the scope of a cap-and-trade program might also give birth to dominant positions shall not be neglected. Recall that in a cap-and-trade program, the regulator sets the cap, and agents freely exchange permits to define their price.

The European Union Emissions Trading Scheme

This section deals with possible design flaws in the allocation of permits on the European carbon market.

The EU ETS Design: An Overview

The European Union Emissions Trading Scheme (EU ETS) has been established by the European directive 2003–7: this regional trading system for CO_2 emissions

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[6]See Guesnerie (2006).

[7]See Muller (2002).

[8]Note that the implicit assumptions of the existence of such an environmental Kuznets curve (the environment is a superior good and environmental regulation becomes stricter through time at higher levels of GDP per capita) are left out of the debate.

[9]See Kolstad (2005).

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covers, across the EU-27 member states, around 11,000 installations[11] representing close to 46 % of Europe's CO_2 emissions. In order to help EU member states to achieve their Kyoto target of reducing emissions by 8 % from those of 1990 level in 2008–2012, the European Union began this commitment in a pilot period from 2005 to 2008. The third European commitment period has started in 2013. Since 2005, the ETS operates independently of the Kyoto Protocol but has been linked to International Emissions Trading (IET) and other flexibility mechanisms in 2007. In this framework, the "Linking Directive" provides the recognition of Kyoto projects credits, Clean Development Mechanism and Joint Implementation credits from the second period in 2008, known as Certified Emission Reductions (CERs) and Emission Reduction Units (ERUs), respectively, for compliance use within the EU ETS.[12] CERs are traded worldwide and not only in Europe as for the EU ETS. Therefore, they can be understood as world proxy for the carbon price.

The EU ETS draws on the US sulfur dioxide (SO_2)[13] trading system for much of its inspiration but relies much more heavily on decentralized decision-making for the allocation of emissions allowances and for the monitoring and management of sources (Kruger et al. 2007). Within the EU-wide Kyoto target, each member state has its own national emissions target as determined under the EU Burden-Sharing Agreement that defines each member state's emissions reduction obligation. Each country is required to develop a National Allocation Plan (NAP), which, among other design features, addresses the national emissions target. A NAP contains the amount of permits allocated to each firm for each country. Each member state has its own registry where changes in the portfolio of its companies are recorded. Furthermore, there is a European Central Administrator, the Community Independent Transaction Log, to oversee the registry systems that will be standardized under European legislation. In that registry, allocations are reflected along with the purchases and sales for each company of the country (Mansanet-Bataller et al. 2007).

The EU ETS is expected to allow for cheaper compliance with the targets under the Kyoto Protocol by letting participating companies buy/sell their emission allowances. In this institutional framework, an amount of two billion allowances has been created each year during phases I and II (before the shift to auctioning in phase III). The EU ETS has started during 2005–2007 with the phase I, followed by phase II during 2008–2012, and phase III during 2013–2020. The price of the allowance is established by the supply and demand of market participants and the level of the scarcity created by the initial allocation.

[11]The definition of an installation effected in the EU ETS is the same as for Integrated Pollution Prevention and Control (IPPC) that is a principal environmental regulatory directive in the EU. Installations are defined as a stationary technical unit where one or more activities covered by the EU ETS are carried out and any other directly associated activities, which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution.

[12]See Table 2 for a quick review of Kyoto units.

[13]The EU CO_2 emissions trading scheme was inspired by successful cap-and-trade programs for SO_2 and NOx in the USA (Ellerman and Montero 2007).

Over-allocation or Relative Success?

The EU ETS gently constrains emissions (8 % reduction for EU-27) so as to enforce a low carbon price. Yet the debate has shifted toward a possible over-allocation of permits. The production decisions of private actors are under scrutiny: do permits surpluses constitute a relative success (i.e., firms have reduced their emissions above projected levels) or an imperfection in the design of the system?

As long as governments continue to allocate allowances to existing facilities based on historic emissions, the scheme is flawed by a perverse "updating" incentive. Firms have indeed an incentive to delay early action in abatement technologies since higher emissions today will be rewarded with bigger allocations in future periods.

Buchner and Ellerman (2008) provide a first empirical assessment of the EU ETS allocation process based on 2005 emissions data. They estimate a slight over-allocation of 4 % during the first period of allocation, while there are strong signs that some emissions abatement measures have occurred. But the analysis is not straightforward since "*a long position is not per se evidence of over-allocation*."[14] The difference between 2005 allocation and verified emissions suggests too many allowances were allocated, but the benchmark against which this conclusion is reached may be biased by insufficient data reporting on emissions before 2005 and by a lack of comparability at the EU-wide level. Firms may also be long because of differences in marginal abatement costs or in expectations (regarding economic activity, energy prices, etc.) under uncertainty.

This section has provided an overview of two major tradable permits market along with their allocation methodology. It revealed a wide range of opportunities for strategic behavior in the design of international permit trading regimes. The presence of countries with large permits holdings increases the probability of price manipulation and the risk of efficiency loss in the allocation of abatement efforts between countries.

Banking and Borrowing Provisions

This section develops three kinds of issues surrounding banking and borrowing: *(i)* the environmental and economic effects, *(ii)* the distribution of the emissions stream through time, and *(iii)* the focus on the EU ETS experience (see also the paper by Chevallier (2012)).

Environmental and Economic Effects of Banking and Borrowing

We review the main effects of banking and borrowing provisions from the theoretical literature and empirical experiences on the environmental performance and

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economic efficiency. When abatement together with endowment of emission allowances is above emissions levels, then regulated industrials bank surplus allowances for potential later use. Thus, an allowance issued for one compliance period may be used by an affected unit for a later compliance period. In the same way, if regulated industrials do not abate enough to cover their emissions level with their allowances endowment, they may borrow allowances from the future allocation. We already know as Haites (2006) noted,[15] "*allowance banking provisions affect basically environmental performance, economic efficiency and market participants' behaviour*." Hence, the regulator's decision of allowing banking creates the significant effects listed below:

Environmental effects:

- Allowance banking and borrowing change the temporal pattern of emissions and may change aggregate emissions and can have environmental, including public health, effects. Allowance banking and borrowing should facilitate adjustment to changes in the emissions cap.
- Banking provisions could also affect the rate of noncompliance and the resulting excess emissions. Evidence suggesting that allowance banking increases the rate of noncompliance is limited. In their experiments, (Cason and Gangadharan 2006) found that allowance banking increases noncompliance and total emissions in a hypothetical scheme with weak enforcement.

Economic effects:

- Allowance banking links future allowance prices to the current ("spot") market price as stated by Maeda (2004).
- Allowance banking and borrowing should improve liquidity[16] in the allowance market. Allowance banking tends to increase the quantity of allowances available to the market and increase the volume of allowances traded. In their experiments, Godby et al. (2000) and Cason and Gangadharan (2006) find that allowance banking increases trading activity.
- Allowance banking and borrowing should improve price stability. If banking is not allowed, allowance prices are likely to be unstable at the end of each compliance period. With no banking, if actual emissions are lower than the cap for the compliance period, the price of allowances should fall to zero at the end of the period since any remaining allowances have no value. With no banking, if actual emissions are higher than the cap for the compliance period, the price of allowances should rise sharply at the end of the period. Allowance banking should dampen such end-of-period price fluctuations and improve price stability.

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[16]The liquidity market is defined as a market where a large volume of trades can be immediately executed with minimum effect on price (Kyle 1985).

These theoretical considerations on the banking provisions are also supported by Ellerman et al. (2000) on the US Acid Rain Program and by the results of a business simulation game and controlled experiments (Schleich et al. 2006) on the EU ETS. The US Acid Rain Program has been one of the most successful attempts to introduce tradable permits markets in environmental policy. That is why the EU ETS draws mostly on it.

The US Acid Rain Program provided empirical support to the view that market-based instruments may be more environmentally efficient than command and control regulation. SO_2 emissions fell, and the program was characterized by a quick implementation, a positive role of banking (twice as much as required), a good compliance, and no hot spots.[17] These optimistic results may be limited to flow pollutants since for stock pollutants like CO_2, the incentive to abate is less temporally and spatially constraining.

As documented by Ellerman and Montero (2007)[18] for the US SO_2 Program, "*banking of allowances remains the predominant form of emissions trading in Phase I (...) nearly three-quarters of the 9.5 million allowances freed up for emissions trading in the first three years of Phase I were banked for later use in Phase II*." This citation confirms the view of banking and borrowing as a key determinant for the success of a program.

In fact, the salient example is the US Acid Rain Program, where banking has been a major form of emissions trading (Ellerman and Montero 2007; Ellerman et al. 2000). During the first 5 years of the program constituting phase I, 1995–1999, only 26.4 million of the 38.1 million permits distributed were used to cover emissions. The remaining 11.65 million allowances (30 % of all the distributed allowances) were banked and have been gradually consumed during phase II (2000 and beyond). As a result, the phase II cap was expected to be reached sometime between 2008 and 2010. Ellerman et al. (2000) analyze in depth the efficiency of this banking behavior in the Acid Rain SO_2 program. The economically optimal level of banking depends first on the SO_2 emissions in the absence of the trading scheme, second on the SO_2 emission reduction cost function, and third on the discount rate. Using ranges of reasonable values for the discount rate and the rate of growth of SO_2 emissions in the absence of the trading scheme, Ellerman et al. (2008) find that banking behavior has been reasonably efficient during phase I and the first few years of phase II. We report in Table 1 the main features of banking provisions in existing trading schemes.

In a game simulation of the EU ETS, Ehrhart et al. (2005) find that a ban on banking pre-2008 allowances into 2008–2012 leads to an inefficient adjustment to the more stringent cap assumed for the latter period. In their simulation of the EU Emissions Trading Scheme, the ban on banking leads to a low price for allowances during 2005–2007 and underinvestment in emission reduction measures. The more stringent cap triggers a price spike during 2008 and 2009. The higher allowance

[17] Typically, the *cheapest* abatement source is found where the *larger* sources are located.

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Table 1 Summary of banking provisions and liquidity data for different emissions trading schemes

Scheme	Gas	Banking and related provisions	Bank amount	Allowances traded as % of annual emissions
Current emissions trading schemes				
Acid Rain Program for electric utilities	SO_2	No limit on allowance banking	11.62 million	75–180 %
RECLAIM (Greater Los Angeles Area)	NOx	No allowance banking; can sell surplus allowances to a buyer with a later compliance deadline and buy allowances with a later vintage	0	20–125 %
	SOx	idem	0	10–105 %
Future emissions trading scheme				
Kyoto mechanisms	GHGs	Banking of different units from 2008–2012 period to the subsequent commitment period is restricted as follows:		
		RMUs may not be carried over		
		ERUs, which have not been converted from RMUs, may be carried over up to a maximum of 2.5 % of the party's assigned amount		
		CERs may be carried over up to a maximum of 2.5 % of the party's assigned amount		
		CERs and lCERs may not be carried over		
		AAUs may be carried over without restriction		
		The quantities of RMUs, ERUs, CERs, tCERs, and lCERs are likely to be small relative to the quantity of AAUs, so the banking restrictions can effectively be avoided by using units other than AAUs first for compliance and then banking surplus AAUs		

prices induce overinvestment in emission reduction measures, which causes the price to fall back to the optimal level by 2012.

The comparison of the banking case with the banning banking case is based on the assumption that prices will develop differently in the two cases (Ehrhart et al. 2005):

- If banking is allowed, it is reasonable (under some assumptions like participants having complete information and emission targets being known) to expect that the price development does not exceed Hotelling's rule (i.e., prices develop according to the interest rate or more slowly). Otherwise, arbitrage between periods is possible (Kling and Rubin 1997). In practice, excess emissions permits can be saved for future use or present emissions can be extended for future abatement. As a result, the permit price becomes arbitraged over time.
- In the banning banking case, a lower price is assumed in the first period than in the free banking period case because first period allowances cover only one period instead of two. Analogously, the price in the second period is assumed to be higher due to increasing scarcity of allowances in comparison to the banking case.

Distribution of the Emissions Stream Through Time

Another question needs to be addressed when assessing the relative merits of allowing banking and borrowing in tradable permits systems: how do firms adjust their emissions stream when they benefit from the possibility to freely bank and borrow permits?

A key issue lies in the discount rate picked by firms. Higher or lower discount rates imply respectively more or less borrowing, while a zero discount rate leads to the same level of pollution at each period.

Our analysis therefore highlights potential *negative* consequences of the use of unrestricted borrowing: the concentration of emissions on early periods by delaying abatement decisions and borrowing may aggravate environmental harm. The positive effects of banking on total present environmental damages are reversed, and the level of global pollution is higher than in a situation without borrowing.

Concerning banking, firms invest in abatement technologies and bank allowances when they anticipate an increase in abatement costs superior to the discount rate; otherwise they would not bear additional abatement costs in the current period. This mechanism corresponds to a situation where standards are stricter through time, which is often the case. In the presence of a convex damage function coming from emissions and stricter future standards, the decision to allow banking *reduces* social damages.

This *positive* effect of banking counterbalances the negative aspects of borrowing detailed above and gives us a more precise picture of the task of the regulator when tailoring regulation for permit trading systems. When social damages are an increasing function of the pollution level at time *t*, our policy recommendation consists in authorizing banking and enforcing stricter pollution standards through time. When the cap is constant or becomes less constraining, the decision to allow borrowing leads to either increasing social damages or decreasing costs for firms.

We have seen how permits alter the *timing* and the *magnitude* of marginal damages. We address in the next paragraph the question of introducing a non-unitary Intertemporal Trading Ratio (ITR) including interests on banking and discouraging borrowing to correct these unwanted permits path.

On the Use of the Intertemporal Trading Ratio

In this section, we evaluate the merits of a modified model of banking and borrowing that explicitly takes into account the distribution of the emissions stream through time. Using the interest rate on allowance balances, the regulator may change the time profile and cumulative quantity to approximate more nearly the social optimum.

There are two sources of inefficiencies that might affect the social optimum:

1. The discount rate used by firms
2. The fact that total damages depend on the distribution of the emissions stream through time

A modified banking system may correct the first type of inefficiency highlighted above, but not necessarily the second type.

Due to the effect of discounting future abatement costs, we need to penalize borrowing by an ITR exogenously chosen by the regulator[19] so that if firms borrow a lot of allowances in early periods, they will reimburse more allowances than actually used in the next period.

This "banking and restricted borrowing" according to Kling and Rubin's (1997) contribution yields the following comments:

- Setting $ITR < 1$ provides an efficient incentive to banking, since firms need to reimburse **more** allowances in second period than were borrowed in first period.
- The weight of debt is greater under a modified banking system than under the original system.
- Such a modified banking and borrowing system allows the private and social solutions to converge, assuming constant and linear social damages.

Assuming both banking and borrowing are allowed and there is a positive private discount rate, the introduction of an ITR yields:

- Concerning banking, the opportunity cost of not using the permit is compensated by the ITR payment.
- Concerning borrowing, for each ton of CO_2 non-abated, the gain from agents' private interest rate is reduced by the ITR.
- The primary effect of a nonzero ITR is on time profile, not quantities: there is a change in marginal stock damages over time (more banking and less borrowing relative to a permit system without ITR) and a small effect on quantities intertemporally exchanged.

For greenhouse gases, the optimal rate of intertemporal substitution has been suggested by Leiby and Rubin (2001) as being "*the ratio of current marginal stock damages to the discounted future value of marginal stock damages less the decay rate of emissions in the atmosphere*[20]," increased by the difference between the firm's discount rate and the social planner's discount rate. This result is obtained in a different setting since they distinguish between *flow* (emissions flow) and *stock* (accumulated) pollutants. Typically, CO_2 emissions are characterized by stock damages that do not stop at the end of the program.

We have seen in this section that the correct determination of the intertemporal discount rate may yield greater efficiency gains. With reference to the discussion on the intertemporal trading ratio above, we may cite several time devices used in

[19] Kling and Rubin (1997) suggest the implementation of a discount rate equal to the industry average rate of interest used to finance medium-term capital expenditures (p. 112).

[20] p. 251

tradable permits programs: the Progressive Flow Control in the US Northeastern NOx Budget Program, changed redemption ratios in US Clean Air Interstate Rule (2:1 from 2010; 3:1 from 2015), and growth indexed caps.

To sum up, characteristic features of intertemporal emissions trading include the fact that at the equilibrium abatement costs are equalized among sources and that the distribution of emissions through time need not yield to a concentration in early periods. The decision to allow or not borrowing depends on the arbitrage between the firm's cost efficiency and a higher pressure on the environment. Firms tend to use borrowing if the environmental constraint is constant or does not become a lot stricter over time. That is why it is recommended to introduce a discount rate specific to borrowed allowances.

Prospective Use of Banking and Borrowing in the Kyoto Protocol

This section offers a description of the possible use of banking and borrowing in the Kyoto Protocol. On the one hand, provisions on banking are cited by Klepper and Peterson (2005)[21]: "*Assigned Amount Units (AAUs) resulting from the Kyoto commitment can be banked without a time constraint. Credits from Joint Implementation (JI) or Clean Development Mechanism (CDM) can be banked up to a limit of, respectively, 2.5 % and 5 % of a Party's initial assigned amount. Sink credits can not be banked.*"

On the other hand, implicit provisions on borrowing may be found in the United Nations Framework Convention on Climate Change or UNFCCC (2000) report.[22] As explained by Newell et al. (2005)[23]: "*International climate policy discussions have implicitly included borrowing within possible consequences for noncompliance under the Kyoto Protocol, through the payback of excess tons with a penalty (*i.e.*, interest).*" This penalty could be fixed to 40 % of additional emissions reduction for the next period of the Kyoto Protocol despite uncertainties regarding the enforcement of this particular provision. This question is addressed in depth by Alberola and Chevallier (2009).

In the next section, we discuss the efficiency of the EU ETS intertemporal market. We also question the presence of institutional learning in the EU ETS.

A Focus on the EU ETS Experience

The EUA price path reflected the evolution of market participants' expectations about the scarcity of allowances. Beginning at 8€ on January 1, 2005, EUA prices increased to around 30€ in July 2005, fluctuated during the six following months in the range from 20€ to 25€, then to 30€ until the end of April. This price development surprised most experts and market participants. According to

[21]p. 295

[22]Paragraph II.XV

[23]p. 149

Sijm et al. (2005), the increase was largely due to political decisions on unpredictably strict national allocation plans, but the market reaction was to some extent exaggerated. Behind the price increase there were also high fuel prices, cold weather, the absence of suppliers in the market, and uncertainty about the political environment (Lecocq and Kapoor 2005). The price fell suddenly at the end of June because of weaker UK gas price and the entrance of Czech Republic into the market. The price fluctuated around 21–23€ for the rest of the year. At the beginning of 2006, the price increased to way above 25€ in consequence of cold weather and high fuel prices. For a couple of months the price stabilized, and then it reached a maximum of over 30€ in April driven by fuel prices.

Around April 25, 2006, first rumors occurred about contents of the national emissions reports for the first year of compliance by the EU member states. The official publication of these emissions reports on May 15 verified the rumors. It became apparent that the market was not as short as expected; especially the power producer needed less EUAs than anticipated (Seifert et al. 2008). The release of the emissions data had a market effect on EUA prices, causing a sharp break in the price of all maturities of EUAs. There were further less severe price fluctuations until the complete data were released on May 15; however, the essential adjustment was made in these 4 days, and after May 15, the spot price remained close to 15€ until late September when a further less-pronounced adjustment occurred.

As noted by Buchner and Ellerman (2008), "*this price "collapse" demonstrated a readily observable characteristic of markets of reacting quickly (and from the standpoint of some, brutally) to relevant information*." This is a significant sign of the informational efficiency of the EU ETS. The EUA market can be considered as efficient if prices fully reflect all available relevant information divulged. And there should be no doubt that the release of reliable information concerning emissions covered by a cap-and-trade program is highly relevant. According always to Buchner and Ellerman (2008),[24] "*one plausible explanation is that market observers had over-estimated the level of CO_2 emissions and the demand for allowances caused by rising real output, the adverse weather in 2005, and the higher prices for natural gas relative to coal. But, another more intriguing possibility is that market observers under-estimated the amount of abatement that would occur in the first year of the EU ETS (. . .)*." The cap is always known, but until the release of aggregate emission data, no one has a really good idea of either the level of aggregate emissions or how much emission reduction/abatement is required to comply with the cap. The same phenomenon was observed in the US SO_2 emissions trading program when the first auction revealed emissions and the implied demand for allowances to be much less than expected (Ellerman et al. 2000). Each year, the European Commission will disclose the verified emissions, playing the role of a "banker." After a new increase to 20€ in June, EUA prices stabilized in a range from 15€ to 17€ and then, in consequence of a less cold winter, they have been

[24] p. 33

declining these last 3 months. Recall that European Union Allowances are the carbon trading unit that is exchanged under the EU carbon permit scheme for each ton of carbon dioxide emitted in the atmosphere.

With two trading periods, EU ETS futures markets are divided in two segments which respond to two distinct fundamentals. As it approached the end of 2007, the EU ETS was characterized by two price signals responding to different dynamics, because of the very limited opportunity to carry over unused EUAs from phase I to phase II. While the prices of spot and futures contracts for the first period were down sharply, the prices of futures contracts for the second period surpassed 18€/t. This increase of the second period allowance price is primarily due to institutional factors: the European Commission issued its opinion on ten National Allowances Plans for the second period since the end of November 2006. In doing so, it established the basis for the institutional framework for 2008–2012 and gave indications regarding three factors that will have a decisive effect on the allowance price:

- The Commission has requested that the allowances awarded to installations be reduced. The Commission also reaffirmed its rejection of ex post allowances based on adjusted projections of growth and emissions. Brussels has therefore sent a clear signal of the scarcity of the allowances that will be available in 2008–2012.
- The possible carryover of unused allowances from the first to the second period ("banking") is now subject to conditions that are so restrictive as to make it practically impossible. Nevertheless, banking between the second and subsequent periods is still permitted, which could further increase the scarcity of allowances in 2008–2012.
- The use of credits originating from project mechanisms created by the Kyoto Protocol (JI and CDM) has been significantly restricted. Ireland has thus been forced to reduce its ceiling from 50 % to 21 %, which corresponds to 35 MtCO_2 less over the period; Sweden will have to reduce its own ceiling from 20 % to 10 %, i.e., 11 Mt CO_2 less than planned.

As Ellerman and Parsons (2006) noted,[25] "*it is virtually certain that the EU ETS will then be either long or short; the likelihood of a perfect match between 1st period EUAs and emissions are extremely small. This binary outcome places a limit on 1st period prices that, when coupled with the constraint on inter-period banking, allows a probability of shortage to be calculated taking into account all the uncertainties weather, economic growth, energy prices, and the abatement response to carbon prices.*" Without banking between the two trading periods, they measure the probability of shortage at any point in time by the ratio of the first period price to the second period price plus 40€, which represents the penalty. The penalty will be 100€ thereafter and companies will also have to surrender a compensating amount of allowances.

[25]p. 1

To wrap up, during the first 3 years, banking and borrowing of allowances are allowed. Therefore, we can expect that first period CO_2 prices follow Hotelling's rule which in its simplest model predicts that, under perfect information, the price of an exhaustible resource will rise at the rate of interest r. However, in the case of the ban of banking between the two periods 2005–2007 and 2008–2012, we highlighted a total disconnection between each exchange market and a decline of the first period prices.

Evidence of Institutional Learning Within the EU ETS

The previous discussion suggests that EUA prices are affected by institutional events such as the simultaneous release in April 2006 of 2005 verified emissions by the Walloon Region of Belgium, France, and Spain. Trading based on information before this price adjustment may be characterized as hazardous or speculative, and only these 2005 verified emissions could give a hint about the long and short positions at the installation level. Most of the verified emissions were reported by mid-May. The fact that the EUA price responded quickly to such relevant information may be interpreted as a strong sign of the efficiency of the intertemporal market in the EU ETS. The EU Commission has greatly learned from the 2005–2007 warm-up period. Namely, most of the issues regarding banking and borrowing have been fixed between 2007 and 2008. The transition from phase II to phase III has mostly been characterized by a change in the allocation methodology, going from free allocation (i.e., grandfathering) to actually having to bid for permits (i.e., auctioning).

Additional Flexibility Mechanisms

In this section, we highlight the possibility for firms to achieve their abatement targets not only by intertemporal emissions trading but also by getting credits from projects (Clean Development Mechanism, Joint Implementation, Domestic Offset). Firms may also take advantage of other tradable permits markets options designed to stabilize prices, such as a safety valve or minimum-price auctioning. Table 2 provides a useful glossary of Kyoto units.

Clean Development Mechanism and Joint Implementation

Projects provide more flexibility to operators to fulfill their obligations and increase market liquidity. The use of credits generated by projects, additionally to the number of allowances distributed, may reduce EUA prices even in the presence of high transaction costs for early projects. It also enlarges the range of abatement opportunities for firms and may lower the compliance costs if it is cheaper to invest in JI or CDM projects than trading.

But this hypothesis crucially depends on the relative price of credits, the possibility to access project credits at a lower cost than through trading on the

Table 2 Glossary of Kyoto units

Assigned Amount Unit	AAU means a unit derived from an Annex 1 Party's assigned amount. They are tradable units that Annex 1 Parties may count toward compliance with their emissions target. Each AAU is equal to one ton of carbon dioxide equivalent gases
Certified Emission Reduction	CER means a unit issued pursuant to Article 12 of the Kyoto Protocol. These are tradable units generated by projects in non-Annex 1 Parties under the Clean Development Mechanism. They may be counted by Annex 1 Parties toward compliance with their UN and EU emissions target and are equal to one ton of carbon dioxide equivalent gases
Emission Reduction Unit	ERU is a unit issued pursuant to Article 6 of the Kyoto Protocol. These are tradable units generated by projects in Annex 1 Parties under Joint Implementation. Annex 1 Parties may count them toward compliance with their emissions target. Each ERU is equal to one ton of carbon dioxide equivalent gases
Removal Unit	RMU is a tradable unit issued on the basis of removals of greenhouse gases from the atmosphere through LULUCF activities under Articles 3.3 and 3.4 of the Kyoto Protocol. Annex 1 Parties may count them toward compliance with their emissions target. Each RMU is equal to one ton of carbon dioxide equivalent gases.

Note: These are units derived from Annex 1 Party's emissions target under the Kyoto Protocol. They may be counted by Annex 1 Parties toward compliance with their emissions target and are equal to one ton of carbon dioxide equivalent gases. AAUs, RMUs, ERUs, and CERs are Kyoto units.

market, and the size of the firm (due to informational and administrative requirements). If banking allows to reduce uncertainty on the delivery of CDM or JI projects, those two instruments may be complementary.

From the viewpoint of economic rationality, carbon assets delivered by projects (be it AAUs, EUAs, CERs, or ERUs) should be fungible. This question implies creating gateways between different frameworks. As the second period of the EU ETS coincides with the first commitment period of the Kyoto Protocol, every transaction of EUA is simultaneously backed by a transfer of AAU between the registries of the different countries concerned. The Linking Directive recognizes JI/CDM credits as equivalent to EU ETS allowances. To maintain a single currency within the EU ETS, the participant delivers project credit to the national authority and gets issued an allowance in exchange for it.

Since credits from the CDM projects can be used for compliance during both phases of the EU ETS,[26] they should cap the price of 2008 allowances and provide a better long-term price signal than the price of 2005–2007 allowances to guide decisions as to which emission reduction measures are cost-effective during 2005–2007. No JI credits are available before 2008.

In this context of interlinked schemes at the regional and international levels, the price stabilization properties of banking and borrowing may prove to be useful to convey a unique carbon price. Next, let us discuss innovative schemes at the domestic level.

[26]As soon as they are connected by the International Transaction Log

Domestic Offset Projects

According to Egenhofer and Fujiwara (2007), "*domestic offset projects (DOPs) mirror the concept of project mechanisms articulated in the Kyoto Protocol, but are used within the home country to reduce emissions in the non trading sectors*."

Those voluntary agreements may incentivize low cost reductions in non-ETS sectors that were not identified previously due to the diffuse nature of polluters, provided the reductions are additional. In return, installations get credits in their respective carbon market.

To overcome the potential complexities of administrative requirements for small units and to keep transaction costs at low levels, there is a need for pilot schemes with simplified rules for additionality, baselines, and discounting and that allow pooling.

Some examples may already be found in New Zealand, New South Wales (NSW 2006), and proposals have emerged in Canada (Bramley 2003) and in the USA at the regional level.[27]

An experimental scheme is currently being implemented in France by the CDC Climat. Eligible projects have a concentration on waste, renewable energies, agriculture, and forestry but also concern the sectors of transport and energy efficiency. Within the JI framework, the CDC Climat selects for each project a foreign partner and will buy at a predetermined price ERUs that will be granted by the French government. The upper limit is set to five million ton equivalent CO_2 between 2008 and 2012. Those emission reduction projects will impact the Kyoto target by an equivalent reduction in the national inventory.

Such an innovative scheme is designed to foster the discovery of new low-cost emission reduction sources at the national level. However, its development may be hampered by the EUA price volatility that we commented above. That is why we recommend the adoption of a clear EU-wide institutional framework where a careful use of banking and borrowing may contribute to dampen allowance price fluctuations.

Next, we discuss another flexibility mechanism to limit price volatility called a safety valve.

Safety Valve

Some propositions to cope with the EUA price volatility deal with the inclusion of a "safety valve" in the EU ETS.

A safety valve is a hybrid instrument to limit the cost of capping emissions at some target level whereby the regulator offers to sell permits in whatever quantity at a predetermined price. If prices are greater than expected, the marginal cost of

[27]See for instance the Regional Greenhouse Gas Initiative at *http://www.rggi.org/* and a review of regional initiatives by Roy (2007).

abatement would be limited to the safety valve price. The regulator tries to set the emissions cap at a level where the expected marginal cost of meeting the constraint will match the beliefs about marginal benefits. To avoid being too far away on the high-cost side, the regulator includes a provision to sell emissions permits at some price near that expected cost level.

Jacoby and Ellerman (2004) report this idea emerged out of discussions in the USA around the costs related to the Kyoto Protocol as a way of raising the likelihood of Protocol's ratification by blunting criticism that the cost of meeting the Kyoto targets would be too high. The best example to date of a system that would have required a safety valve is the RECLAIM Program in California.[28]

The inclusion of a safety valve to a tradable permits market is not new, despite strong criticisms about this instrument:

- If the safety valve price is too high, it will have no effect.
- If the safety valve is too low, the quantity constraint is not binding anymore and may be associated with a permanent tax.
- There is a potential loss of "environmental integrity," i.e., a fear of relaxing toward target reduction instead of supporting economically efficient implementation.

These negative effects lead us to be skeptical about the inclusion of a safety valve as a policy recommendation for the EU ETS.

Finally, we discuss another flexibility mechanism linked to the allocation process.

Minimum-Price Auctioning

To improve the stability of EUA pricing during 2005–2012 (before the shift to auctioning), the National Allocation Plans may have included a provision to allocate permits not only by grandfathering, whose "updating" effects based on past emissions may be detrimental to the efficiency of the scheme, but also by auctioning. While it is beyond the scope of this paper to deal with auctioning mechanisms in detail, it is worth emphasizing the benefits of a specific technique called "minimum-price auction" whereby governments could fix a minimum bid level that would serve as a price floor.

[28]According to Harrison (2003), this multisource program regulating SO_2 and NO_x emissions had overlapping control cycles and trading between control groups, so de facto 6-month banking and borrowing. But the temporal flexibility was not enough for such a limited geographic scope, and as unusual weather conditions and lack of new capacity placed high demand on existing units, the permit price rose from $5,000 to $90,000 per ton, i.e., multiplied by 18. The disconnection of electricity and environmental markets associated with other program design failures led the State to eventually take over and provide adequate electricity supply. At the same time, prices of future vintages (borrowing) revealed the short-term nature of the crisis and recognized that it was an unusual case. This experience raises the question of adding several sectors in the same permit market like the EU ETS: wouldn't it be preferable to have different prices for different markets?

Such an allocation process requires a certain degree of coordination between member states on basic auction rules, while the Commission supervises its enforcement as for each NAP. This device guarantees that prices will not drop below a predetermined level and helps restoring confidence in the efficiency of the EU ETS for market participants. But it needs to be configured in accordance to the quantitative limit on projects that might enter the EU ETS for instance.

In this section, we stressed that the banking and borrowing mechanisms should not be seen in isolation of other flexibility mechanisms that firms could use to achieve compliance at a lower cost. Those include mainly projects (JI, CDM, DOP), whose efficiency may be increased by a careful use of banking and borrowing. We discard the use of a safety valve as a useful flexibility mechanism, but we recommend political savvy in auctioning permits using a minimum price.

Conclusion

This chapter summarizes the main functioning principles of tradable permits markets for use in environmental regulation along two dimensions: initial allocation and intertemporal trading.

Among the international emissions trading schemes, we may cite the Kyoto Protocol and the EU ETS. From a political economy perspective, this chapter highlights the difficulties encountered by the European Commission during the validation of the EU ETS Second National Allocation Plans where each national regulator needs to arbitrate between various interests at stakes and reveals the necessary compromise that needs to be found between various conceptions on the role of environmental regulation.

The negotiation process of each NAP at the member state level is typically an example of a manipulable rule whereby industries may conduct lobbying activities to extract more permits as a monopoly rent. With reference to the debate “rules versus discretion” in monetary economics, this unhealthy lobbying by major industries calls for further research to ascertain the conditions under which it would be optimal to delegate the determination of the cap and the distribution of permits to an independent agency (Helm et al. 2003).

Regarding intertemporal flexibility, the theoretical studies agreed on the fact that when it is effective, banking and borrowing allow a reduction of climate policies costs. The incentive to bank emerges more especially with more stringent future environmental targets. Our review of the main theoretical results on the use of banking and borrowing for tradable permits markets provides a balanced picture of the pros and the cons of this instrument: while banking provides incentives for early compliance, unrestricted borrowing may aggravate the environmental harm by a concentration of the emissions stream over specific periods.

Combined with generous and free permits endowments, this situation confirms the view that the EU ETS is only “warming up” in its first phase at the expense of suboptimal abatement choices. The regulator could adopt an intertemporal trading ratio specific to borrowing as discussed by Kling and Rubin (1997), allowing for a better grasp of the possibilities offered by intertemporal emissions trading.

Indeed, a greater reliance on banking and limited borrowing (i.e., with a specific discounting factor) should be promoted to allow firms to smooth their emissions and take investment decisions in abatement technologies with a better capacity to react to the evolution of the carbon constraint over time.

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Strategic Environmental Assessment as a Tool to Integrate Climate Change Adaptation: A Perspective for Nigeria

Chika Ubaldus Ogbonna and Eike Albrecht

Contents

Abstract

Nigeria is one of the countries in sub-Saharan Africa vulnerable to current and future climate variability and change. The effects of climatic changes in Nigeria would vary significantly and set to occur in several regions of the country and all sectors of the economy. Climate change is a great challenge to the sustainable development and the Millennium Development Goals (MDGs) in Nigeria. The main purpose of this chapter is to highlight the challenges associated with the current and projected impacts of climate change on the human environment

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in Nigeria, to review and explore the potentials of Strategic Environmental Assessment (SEA), and to propose its use in making informed decisions relevant to the implementation of the newly established adaptation programs in the country. Current measures on how Nigeria is responding to recent impacts of climate change are presented. It is imperative that an appropriate environmental assessment tool such as SEA be employed in making rational decisions regarding adaptation options. SEA offers a structured and proactive environmental tool for integration of climate change adaptation into formulating policies, plans, and programs (PPPs) across relevant sectors.

Keywords
Nigeria • Climate Change • Adaptation • Strategic Environmental Assessment (SEA) • Decision-making

Introduction

Climate change is occurring and may have more consequences on the human environment in the future. The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), published in 2007, fully confirmed the occurrence of global climate change particularly in developing countries. This report also categorically emphasized that human activities are the main cause of observed changes in climate today (IPCC 2007a). This fact was also restated by the recent published 5th assessment report of the IPCC in 2014 (IPCC, 2014, p. 5). Such anthropogenic influences that contribute to climate change include the burning of fossil fuels, the combustion of biomass, agriculture, and deforestation. According to a German Watch Report, more than 710,000 people have lost their lives as a result of direct effects of over 14,000 recorded extreme weather and climate events which resulted in some damages worth above USD 2.3 trillion (in Purchasing Power Parity) observed globally between 1991 and 2010 (Harmelling 2011, p. 4).

The UNFCCC has already identified adaptation as an option to address climate change. Adaptation in the context of climate change refers to any adjustments that take place in natural or human systems in response to actual or expected climatic stimuli or their effects or impacts, aimed at moderating harm or exploiting beneficial opportunities (Klein 2004; IPCC 2007b; IPCC 2014). "Adaptation, therefore, includes several types of actions (direct protection of people and assets, actions to support this protection, reactions with respect to impacts, etc.), which can be implemented in several sectors such as (agriculture, water, energy, transportation, infrastructural development etc.), associated with different climatic challenges depending on geographic scales and zones (coastal, mountains, urban areas, etc.) and using widely diversified instruments (standards, information, tax measures, transfers, investment choices in infrastructure, etc.)" (IPCC 2007b cited in Hallegatte et al. 2011, p. 3).

To deal with the impacts of climate variability and change in Nigeria, there is a need for robust adaptation measures to be implemented. The United Nations

Framework Convention on Climate Change (UNFCCC) which entered into force on 21 March 1994 provides the basis to adapt to climate change impacts. Nigeria signed the convention on 13 June 1992; its ratification took place on 29 August 1994 which entered into force from 27 November 1994. Article 4(1)(f) of the UNFCCC urges all members to "take climate change considerations into account, to the extent feasible, in the relevant social, environmental, economic and environmental policies and actions, and employ appropriate methods, for example, impact assessments [such as Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA)], formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects, programs or measures undertaken by them to mitigate or adapt to climate change" (See full text of the Convention).

The Effects of Climate Variability and Change in Nigeria

Climate change is the latest challenge to achieving sustainable human development targets such as the Millennium Development Goals and objectives set out in the Nigerian development agenda termed "Vision 2020" (NASPA-CCN 2011, p. 1). "Nigeria has a long history of changing weather and environmental conditions this is due to its many climatic zones, ranging from the long coastal zone in the South and the large arid area in the North" (NEST and Woodley 2012). Such changes in climate and weather patterns are now on the increase in several parts of the country. Such trends are validated by recent research, for instance, Nwajiuba and Onyeneke (2010) applied regression model and trend analysis of climate data for a period of 30 years (1978–2007) in the Southeast Rainforest Zone of Nigeria. The outcome of this research shows that decreasing trends for rainfall and relative humidity and increasing trends in temperature and sunshine hours pose severe effects on major crop yields such as maize, cassava, and yam which serve as major food crops in the region. The impact of climate change can already be seen across the country starting from the Sahel in the North to the rainforest and coastal zone in the South (BNRCC 2011). A study carried out by Odjugo (2010) shows that air temperature is constantly on the increase, especially since the 1970s. Despite the relative increase in temperature across Nigeria, observational trends in temperature indicate higher temperature anomalies in the semiarid region of the country than the coastal regions (Odjugo 2010, p. 1). In fact, urban areas and cities are facing new challenges of the so-called urban heat islands. The changing climatic conditions are apparent and have become a big challenge in Nigeria today, posing severe effects on social infrastructure and people's livelihoods. Some of the potential effects of climate change and variability in the country include extreme weather events, temperature increase, increase in flooding, coastal erosion, sea-level rise, and long periods of droughts in the North and variability of rainfall in the South. The expected climate impacts in urban areas in the country are likely to include extreme flooding due to heavy storms, heat waves, freshwater scarcity, and extreme weather events. Furthermore, such climate impacts may add more stress to public infrastructures and on urban sectors such as tourism, transportation, energy generation, and agricultural production. For example, flooding is one of the most pressing environmental challenges in Nigeria today. There are three major ways in which flooding occurs in Nigeria, namely, river flooding, urban flooding, and coastal flooding (Gwary 2008; Adeoti et al. 2010; Bashir et al. 2012). The impacts of flooding have been observed in Nigeria for decades. However, increase in flooding as a result of storm surge and variation in sea levels may become more frequent in the country in the future considering global and regional predictions.

There are several projections, which point to increase in sea-level rise in the Nigerian coastal waters. For instance, a rise in sea level of 0.462 m (above sea level) was recorded in the coastal areas between the year 1960 and 1970 (Udofa and Fajemirokun 1978, Boateng (2010, p.13). It is projected by Awosika et al. (1992) that the Niger Delta area of the country could lose more than 15,000 km^2 of land by 2100 with only a one meter rise in sea level. Lagos and the low-lying coastal areas of the Niger-Delta region of Nigeria are predicted to be equally affected by such events (Awosika et al. 1992). Nwajiuba (2008) foresees that important coastal cities in Nigeria such as Lagos, Port Harcourt, Calabar, and Warri are potential areas for inundation exposure as a result of the projected sea-level rise and storm surge events. Moreover, urban flooding has become one of the greatest environmental challenges in most of the Nigerian cities nowadays (Etuonovbe 2011). Settlements

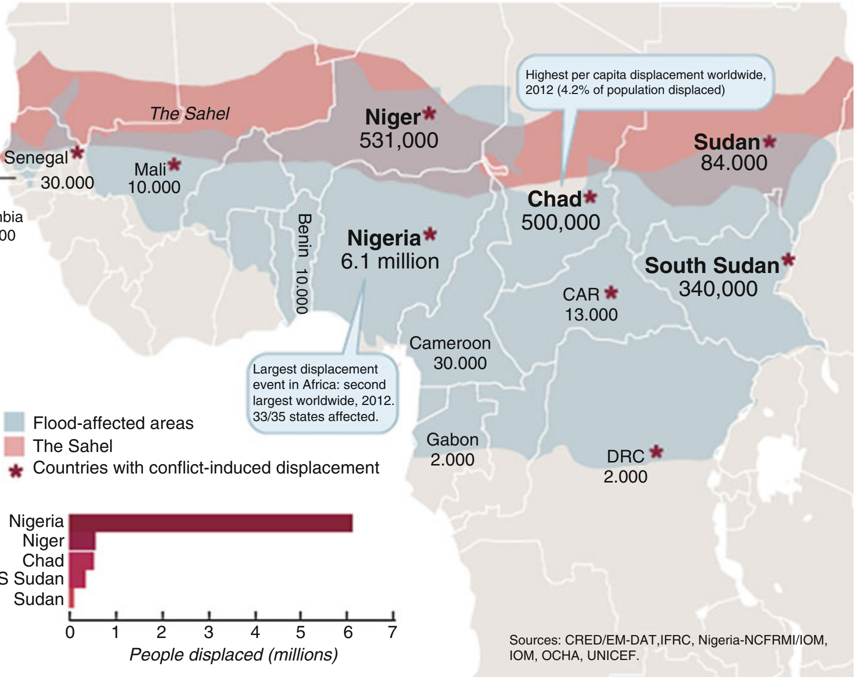

Fig. 1 Map of West and Central Africa flood displacement, June to October 2012 (Source: IDMC/NRC (2013, p. 20))

in the coastal region of Nigeria are being seriously affected due to severe flooding (Uyigue and Agho 2007). Similarly, the International Displacement Monitoring Centre Report (2013) mapped and documented the severe heavy rainfall that affected about 18 countries in Africa from June to November 2012 as can be seen in Fig. 1. The map shows that heavy rainfall event caused flash flooding, inundation, and displacement of vulnerable communities in the region including about 6.1 million people in Nigeria alone.

Factors Increasing Nigeria's Vulnerability to Climate Change

There are several factors that exacerbate the vulnerability of Nigeria to climate change. For example, the rapid shift in Nigeria's demography poses own challenges in the face of climate change. Nigeria's current population is estimated to be about 160 million people and a population density of 138 people per km^2 is growing tremendously (BNRCC 2011, p. 1; Ndujihe 2013). According to a report from the "Building Nigeria's Response to Climate Change project" (BNRCC 2011), increasing population density in the country is an additional pressure on scarce natural resources and food security (BNRCC 2011, p. 1; Nest and Woodley 2011, p. 5). This further increases the vulnerability of the most particularly exposed communities. The rate of population growth and urbanization may also increase vulnerability through inappropriate land-use and land fragmentation. Furthermore, rapid population growth (2.9 % per year) and urbanization with nearly 50 % of the population now living in the urban area has added demand for public infrastructural services (NASPA-CCN 2011, p. 3). This present situation reduces the resilience to a range of climate risks in the country (NASPA-CCN 2011, p. 3). Furthermore, some fast-growing cities and urban areas in Nigeria are mostly situated along the coast and therefore highly vulnerable to the impact of sea-level rise. For instance, the urban and suburban areas of Lagos and the Niger Delta could be adversely affected considering the predictions. The ever-growing coastal slum population living in floating slums and flood-prone wetlands in and around Lagos suburban area is a challenge to urban planning and development. In addition to slum development, the city of Lagos faces a problem of coastal erosion and flooding (Mehrotra et al. 2011, p. 30). Such areas may be drastically affected by climate hazards if the projected climate events would occur (Awosika et al. 1992; Mehrotra et al. 2011, p. 32).

Another factor is land degradation as a result of deforestation and overgrazing in Nigeria (Abiodun et al. 2011, p. 1). This accumulates to large environmental challenges, which have been seen in various parts of the country, in recent times. Climate change would intensify such environmental problems. The incessant oil spillage and gas flaring in the Niger Delta had contributed immensely to the environmental degradation of the region (Ugochukwu and Ertel 2011). Climate change will add to such challenges, as a result will increase the region's vulnerability.

Indeed, both physical and socioeconomic factors dispose Nigeria to the adverse effects of climate change (BNRCC 2010). According to the Nigerian Environmental Study Action Team Report (NEST) (2010), some of these factors include

(1) Nigeria's long coastline (800 km), prone to impacts from the rise in sea level; (2) Nigeria's North prone to drought and desertification; (3) threatened water and energy resources; (4) more than 60 % of the population depends on threatened agricultural and fishing resources; (5) increasing population; and (6) inadequate policies and programs, especially among vulnerable communities and in vulnerable regions. Nigeria is vulnerable to the impacts of climate change largely because approximately 70 % of Nigerians are engaged in smallholder rain-fed agricultural production (NEST and Woodley 2011, p. 10).

In this respect, however, the current and potential impacts of climate change are likely to be different in several parts of the country. For instance, Nigeria's long coastline to the South situated in the coastal/rainforest region implies that a huge number of people living close to the coast are vulnerable to sea-level rise and storm surges, while several communities residing in the Northern part of the country particularly in the Sahel region could experience increased effects of cyclical drought (BNRCC 2011). Current observations in the Sahel region show that the area is susceptible to aridity as a result of increasing high temperatures and reduced frequency of rainfall (BNRCC 2011). Furthermore, biodiversity, coastal settlements, water, agriculture, and land use are expected to be affected by the fast-increasing trend of climate variability in the country.

Policy Response to Climate Change Adaptation

There are several new challenging issues associated with changes in weather and climate deserving adaptation considerations in Nigeria today, perhaps more than the several impacts highlighted as the increase in extreme climatic events pose an enormous challenge to the Nigerian economic growth (DFID/ERM 2009; Sayne 2011). As such, many parts of the country have recorded different kinds of climatic changes, which have led to increase in flooding, heat waves, erosion, and droughts. Erratic increase in rainfall, flooding, and drought, for instance, can reduce efforts being made to achieve sustainable development and the Millennium Development Goal (MDGs) in Nigeria, especially as future vulnerability may not only depend on climate change but also on several other factors such as development pathways (UNFCCC 2010). In this regard, adaptation is essential to reduce the present and future impacts of climate change in Nigeria in order to rescue vulnerable communities, agricultural sectors, ecosystems, and at the same time increase the adaptive capacity of the population.

Globally, awareness on climate change in recent times has been on the increase as well as vulnerability research. As a result, there are several actions from many stakeholders in the public and private sectors especially at the national and local levels that focus on understanding the challenges that besiege climate change issues and what they can do to reduce the associated effects (Hallegatte et al. 2011, p. 3). Such trend is peculiar to Nigeria today although more effort is needed from individuals, nongovernmental organizations, institutions, and particularly from the government, for increasing awareness and public education with respect to climate change adaptation and even on Clean Development Mechanism that targets climate change mitigation in the country. As climate policy objectives are partly formulated at the international level, policies need to be implemented on a national, subnational, or even on the local scale (NEAA 2009, p. 81). The UNFCCC obliges all parties to prepare for adaptation to the impacts of climate change. In recent times adaptation policy has become a focus of researchers and stakeholders as an option to tackle climate change in addition to mitigation. Adaptation in contrast to mitigation is more feasible on a local scale as it addresses specific local impacts of climate change. Moreover, there is not yet an international guideline or perhaps a fit for all approach to adaptation on global scale. This is due to the different levels of vulnerability of social, economic, and ecological systems to myriad consequences of the impact of climate variability and change, and even the cross-sectoral challenges arising from different institutional systems (UNFCCC 2012, p. 4). Recognizing these challenges, increasing number of developing countries has initiated independent adaptation plans and strategies. The coherent approach being taken by these countries aimed to "contribute to efforts towards climate-resilient development, suggesting a long-term continuous process and most importantly periodic revisions" (UNFCCC 2012, p. 4).

Climate Change Adaptation Policy Response in Nigeria

In addition to the drafting of the National Climate Change Policy in Nigeria, the country has also developed adaptation plans that will enable the country to address the emerging challenging issues associated with climate change. The Nigerian national adaptation plan was initiated after accessing the risk and vulnerability of the entire country on current and potential impacts of climate change (UNFCCC 2012, p. 5; Abiodun et al. 2011; NASPA-CCN 2011). The national adaptation plan also considered lessons and knowledge generated from the several project components, such as a research pilot project (e.g., future climate scenario studies, policy development, communication, and outreach as well as youth and gender initiatives (Abiodun et al. 2011). The National Adaptation Plan and Strategy of Action on Climate Change for Nigeria was developed in partnership with the Special Climate Change Unit (SCCU) of the Federal Ministry of Environment of Nigeria and other relevant stakeholders such as the Nigerian Environmental Study/Action Team (NEST) with a financial support from the Canadian International Development Agency (CIDA). The Nigerian National Adaptation Plan has, therefore, been developed in a coherent manner, thereby serving as an exemplary document and a case study on the national adaptation plan for other developing countries that aim to initiate adaptation plans or strategies (UNFCCC 2012). Laudable as the Nigerian adaptation plan could be, there is a need for adequate decision-making during the implementation.

Reminiscence that climate change may lead to loss of between 2 % and 11 % of Nigeria's Gross Domestic Products (GDP) by 2020 and between 6 % and 30 % by the year 2050 as pointed out in the National Adaptation Strategy and Plan of Action on Climate Change for Nigeria. To reduce such potential loss the Nigerian National Adaptation Strategy shows that adaptation planning will take a strategic approach in addressing climate change impacts in the country. Adaptation measures shall focus on all the affected sectors including agriculture (crops and livestock), livelihoods, education, freshwater resources, coastal water resources, fisheries, forest, biodiversity, energy, transportation, communication, industry and commerce, emergency and disaster response, vulnerable groups, migration and security, human settlement and housing, health, and sanitation.

Initiatives for Climate Change Adaptation

Nigeria as a member of the Economic Community of West African States (ECOWAS) plays a key role in developing Climate Change Adaptation Strategies that can help reduce the impacts and consequences of climate change in the region. ECOWAS is making strong efforts to integrate climate issues into economic planning and management at the regional and national scales. The West African Climate Change Adaptation Program initiative is a milestone towards the formulation of the "Regional Plan of Action for reducing vulnerability as climate change impact increases in the West African States" (OECD 2009). Another important step, is a recent establishment of Graduate Programs in two Nigerian Universities under the German initiative on the "West African Science Service Centre on Climate Change and Adaptive Land Use (WASCAL)" which aims to enhance the capacity building in Nigeria and across the West African States.

Furthermore, in order to address the impacts of climate change and global warming in Nigeria and to respond to international obligations, the former president of Nigeria, Olusegun Obasanjo, endorsed the creation of a new unit – "Special Climate Change Unit (SCCU)" – under the Federal Ministry of Environment, Housing, and Urban Development. The unit is established to ensure that the UN conventions and the Kyoto Protocol activities such as the implementation of Clean Development Mechanism and other related issues are effectively addressed. The department has the mandate, to oversee initiatives geared towards reducing climate change impacts on the Nigerian environment and coordinate sectoral measures that can help achieve its goals. The Special Climate Change Unit was commissioned in 2006. Recently it has been established as a full department within the Ministry of Environment. The department is exclusively responsible for coordination of matters relating to mainstreaming climate change adaptation into the national policies. Also, efforts are being made by the Nigerian government, to create a National Climate Change Trust Fund that could help finance strategic actions so as to curb the impacts of climate change (Müller 2013, p. 5).

The Need for Integrated Assessment of Adaptation Options

In order to minimize the impacts of climate change on the most vulnerable communities, integrated assessment of adaptation options is imperative. In this regard, implementation of adaptation measures should be supported by adequate environmental assessment procedures. This is very essential in order to make robust decisions regarding adaptation to the impact of climate change hence such decisions remain complex. However, to reach this target, Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) are the two unique environmental assessment tools that are used internationally for wide-ranging environmental assessment such as prediction and evaluation of social, economic, health, and environmental impacts of a proposed plan (UNEP et al. 2004, p. 6). According to Sadler et al. (2011) "the introduction of SEA has an integral part of the development of EIA." SEA was developed together with EIA in 1969 with the United States National Environmental Policy Act (João 2005, p. 5).

Nigeria does not yet have a legal requirement and a framework for SEA, but EIA is well established. For instance, Adebanji (2010) pointed out that neither policies, plans, nor programs (PPPs) have been regulated under SEA at the national, regional, or sectoral/industrial level in the Niger Delta region of Nigeria considering several social and environmental challenges that need to be addressed in the area (Adebanji 2010, p. 5).

Now, the question is how can the environmental impact of adaptation programs be reduced and positive effects enhanced in order to avoid decisions that may lead to maladaptation. To address this issue, it is important to first identify the kind of adaptation programs that could help reduce the risks posed by a particular climate hazard and at the same time being environmentally conscious. This challenging task could be possibly addressed through the application of appropriate environmental assessment and decision aiding tool such as SEA. Such assessment procedures can also help phase out programs that may pose a risk to the environment while pursuing the win-win option characterized by overarching benefits of climate change mitigation and adaptation. Therefore, SEA is an important tool to be considered in making informed and robust decisions at the early stage before such policies, plans, or programs can be implemented (OECD 2008a, p. 21). EIA can then be used at a later phase with the aim of improving a particular proposed project. The Implementation of the Nigerian Adaptation Strategy and Plan of Action should be considered in this context. EIA is very relevant in assessing the possible impact that proposed projects particularly infrastructural related adaptation may pose on the environment (Agrawala et al. 2010). On the other hand, "the integration of climate change into strategic planning through the application of SEA should lead to better informed, evidence-based PPPs that are more sustainable in the context of changing climate and more capable of delivering progress on human development" (OECD 2010, p. 4). The authors will not go into details on EIA process in Nigeria, and the overall basic principles of SEA; however; it is assumed that the reader is familiar with EIA. In addition, appropriate citations and links will be provided.

Evolution of EIA

There are many driving forces for the use of EIA worldwide. Firstly, EIA serves as an instrument for sustainable development in developed and developing countries though it has its limits, which are sometimes covered through early assessment of

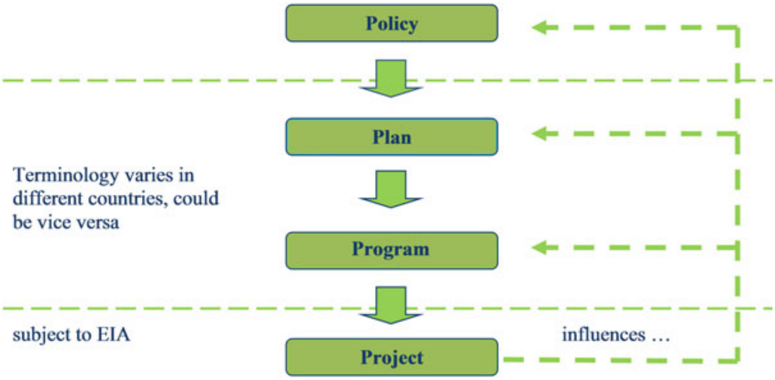

Fig. 2 Links between EIA and SEA (Source: Adapted from Albrecht (2011, p. 156))

three levels of SEA linked to EIA (see Fig. 2). According to Albrecht (2011) one of the reasons for assimilation of EIA by several developing countries is due to the World Bank policy in 1988 which adopted EIA for major development projects. This World Bank operational directive entails that any country seeking development assistance carries out an EIA especially under the World Bank supervision. Henceforth, "EIA of World Bank became mandatory for all projects that may potentially have a significant influence on the environment" (Albrecht 2011, p. 152). The target of the World Bank EIA recommendation is to make sure that projects on funding considerations by the institution are environmentally friendly and sustainable.

A Brief Overview of EIA Administration in Nigeria

Nigeria recognizes the achievement of environmental protection as an integrated policy issue rather than standalone policy targets. The country also seeks to achieve sustainable development through enforcement of adequate environmental policies, laws, and regulations. The EIA Decree No. 86 of 1992 was established under the defunct Federal Environmental Protection Agency (FEPA). The FEPA Act and Regulations were replaced in 2007 by the National Environmental Standards and Regulations Enforcement Agency (NESREA) Act which established the NESREA, giving it the mandate to oversee the protection of the Nigeria's environment through enforcement of these environmental laws in collaboration with the Federal and State Ministry of Environment. Nigeria runs a federal system of government – today the Federal Ministry of Environment is the central environmental authority as it contains the legal requirements to carry out EIA and evaluate the consequences of proposed projects on the environment. The Nigerian Federal Ministry of Environment is therefore bestowed with the mandate of EIA administration in Nigeria. On the other hand, the NESREA is responsible for the enforcement of environmental regulations, rules, laws, policies, and guidelines. NESREA has the entire competence for enforcement of environmental control measures through registration, licensing, and permitting system other than in the oil and gas sector. However, the EIA law and the Urban and Regional Planning Decree No. 88 of 1992 provided principles guiding development of major projects that may likely affect the environment significantly (Federal Republic of Nigeria 1992a, b; Agwu et al. 2000; Ladan 2012b; Ugochukwu and Ertel 2011; Olokesusi 1998).

The Nigerian EIA decree contains the procedure to be followed. In addition, it provides a checklist, for the categorization of projects subject to EIA (Echefu and Akpofure 2003; Ugochukwu and Ertel 2011, p. 18). EIA is mandatory for all major projects that may likely pose significant impacts on the Nigerian environment considering location or size of the project. An example of such projects may include major road construction, industrial and infrastructural development, mining, housing development and projects located in environmental sensitive areas. It is worthy to note that EIA in Nigeria is a licensing tool for proponents, especially those in the oil industry and other mining development to carry out before going ahead with their operations. EIA must be carried out with the input of all the stakeholders and the Ministry of Environment and all other competent authorities. An Environmental Impact Statement (EIS) is usually produced at the end of this process.

Institutional and Legal Challenges of EIA in Nigeria

The Nigerian EIA practices and legal and institutional frameworks have for several years been attributed to several problems and challenges. These include low public access to final EIA reports, insufficient interagency coordination (overlapping of competencies; federal system's challenges), and inadequate stakeholder consultations and public participation. Even though access to environmental information is given by the Decrees No. 86/1992, information dissemination is difficult in practice. Furthermore, full public participation is given but only for 21 days (Federal Republic of Nigeria 1992a; Ugochukwu and Ertel 2011, p. 169; Nwoko 2013, p. 26), and Environmental Impact Statements are not published online. However, it is expected that the Federal Ministry of Environment and the young NESREA will through their good practices and monitoring responsibilities enhance the EIA practice and address such pitfalls recorded in enforcing the provision therein in the past years. More especially as NESREA allows for the collaboration of local and international agencies and nongovernmental organizations including international regulatory bodies such as the UN Agencies, World Bank, Partners for Water and Sanitation (PAWS-UK), United Kingdom Environment Agency (Ladan 2012a), and other interested corporate bodies around the world. Such local and international cooperation could reduce these shortcomings; such cooperation is in the right direction as environmental challenges become more global. However, climate change was not considered during establishment and formal requirement of EIA decree No. 86/1992 procedures; yet, the integration of climate change into the stages of SEA/EIA could be an important step to be realized under the new NESREA enforcement responsibilities and the good practices of the Federal Ministry of Environment in collaboration with relevant environmental departments in the country. Having in mind that climate change is a crosscutting issue, the Federal and State Ministry of Environment, the National and State Urban and Regional Planning Authorities, and other relevant Environmental Agencies can play a key role that could help enhance adaptation decision-making and reduce climate-induced risks.

Aims of SEA

The National Environmental Policy Act (NEPA) established in the United States in 1969 promulgated the first Strategic Environmental Assessment (SEA) regime. SEA is a tool designed to achieve the overarching target of sustainable development, for example, the national targets for the implementation of Agenda 21 and the Plan of Implementation of the World Summit on Sustainable Development known as the Johannesburg Plan of Implementation. The tool being flexible also applies to new environmental challenges such as climate change. The major aim of SEA is to incorporate environmental concerns into strategic decisions which may include policies, plans, programs, regulatory frameworks, and legislations depending on the respective area of application in the SEA provisions. For example, policies and legislations are not included in the area of application of the EU SEA Directive. SEA helps to protect the environment by improving decisions that lead to sustainability targets. The uniqueness of SEA lies in the consideration of environmental concerns from the onset of decision-making in relation to development of proposed plans and subsequent projects such as public infrastructures. Considering the characteristics, "it can be argued that EIA procedure is at times analogous to that of SEA" (João 2005, p. 5). It is worthy to note that countries or nations having an effective EIA procedure as an environmental assessment tool can easily apply SEA using existing EIA institutional structures. This way SEA framework can easily be incorporated within the planning and institutional decision-making procedures. This is possible in the case of Nigeria EIA institutional framework and planning system.

There are two key principles of SEA (João 2005, p. 7). According to João (2005) one of the major principles of SEA is to explicitly identify potential PPPs (or alternatives) and evaluate these alternatives in an assessment context. She emphasized that SEA likewise EIA should not be employed to mitigate environmental impacts of actions that have already been decided upon. Rather the environmental assessment process should be used to inform the decision of what action should take place, i.e., what alternative should be chosen (João 2005, p. 7). The second principle of SEA relates to the improvement of proposals. João (2005) posits that SEA must improve, instead of just analyze policy or programs, meaning that SEA should be effectively used in the formulation of strategic actions: "looking at evolving strategic action afresh and being willing to change and improve such strategies in the light of the SEA findings." Furthermore, the SEA should explicitly contribute to the decision-making process (João 2005). SEA procedure should, therefore, fit more elegantly in the strategic decision-making process (Therivel 2004, p. 61).

There is no common definition of SEA; however, Sadler and Verheem (1996) provides a very well-cited definition; thus SEA is "a systematic process for

Table 1 Some Comparisons between EIA and SEA

EIA of projects*	SEA of policy, plans, and programs**
Takes place at end of decision-making cycle	Takes place at earliest stages of decision-making cycle
Reactive approach to development proposal	Proactive approach to development proposals and programs
Identifies specific impacts on the environment	Identifies environmental implications, issues of sustainable development
Considers a limited number of feasible alternatives	Considers a broad range of potential alternatives
A limited review of cumulative effects	Early warning of cumulative effects and synergistic impacts
Emphasis on mitigating and minimizing impacts	Emphasis on meeting, environmental objectives, maintaining natural systems
Narrow perspective, high level of details	Broad perspective, lower level of details to provide a vision and overall framework
Well-defined process, clear beginning and end	Multistage process overlapping components, policy level is continuing iterative
Focus on standard agenda, treats symptoms of environmental deterioration	Focuses on sustainability targets, get at source of environmental deterioration

Source: CSIR (1996) cited in UNEP (2002, p. 495)
*EIA usually assesses only negative effects on the environment
**SEA (for example the SEA-Directive of the EU) assesses positive and negative effects of plans and programs

evaluating the environmental consequences of proposed policy, plan or program initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision making on par with economic and social considerations." Similarly, João (2005) provides a brief definition thus SEA is "the process of evaluating the environmental impacts of proposed PPPs, in order to inform decision making." One of the main differences between EIA and SEA is that the scope and processes of the latter are characterized by greater diversity (UNEP 2002 p. 493). Furthermore, the SEA "process extends the aim and principles of EIA upstream in the decision-making process, beyond the project level and when major alternatives are still open" (UNEP 2002, p. 493). SEA represents a proactive approach to integrate environmental considerations into the highest level of decision-making, consistent with the principles outlined in Agenda 21 (UNEP 2002, p. 493). Both SEA and EIA have common elements, although increasing modifications to the procedure and methodology are necessary when moving from the project to the policy level (UNEP 2002, p. 493). While EIA is widely practiced, SEA is increasingly being recognized in several developed and developing countries and international and local organizations as a better tool to make informed decisions and improve developmental programs. Table 1 shows a comparison of the key characteristics of both processes as is given by UNEP (2002, p. 493).

The link between SEA and EIA is established in a tiered manner. According to João (2005) SEA deals with a hierarchy of strategic actions, which ultimately affects what projects are built on the ground (Oxford Brooks University 2004 cited in João 2005). “This hierarchy might differ in detail from country to country but it is usually there, and it is a key aspect of what SEA is all about” (João 2005, p. 5). According to Albrecht (2011) the hierarchical order is ideal as plans and programs usually set a framework for the subsequent project realization (Albrecht 2011, p. 155). The tiered concept helps in sustainable decision-making regarding the implementation of PPPs and any project under such developmental process. SEA is, therefore, largely linked to EIA (Albrecht 2011, p. 155). Figure 2 shows the linkage between policy, plan, and program of SEA and project-specific EIA. It is to be noted that the words policies, plans, and programs are used differently in countries considering the best-suited terminology (Sadler et al. 2011, p. 2; Albrecht 2011, p. 156). However, it is important to define the meaning of policy, plan, and program (PPP) as used in this context. A policy is an inspiration and guidance for action; a plan is a set of linked proposed action with a specific time frame that will implement the policy, while a program can be regarded as a set of proposed projects in a particular area that will implement the plan (João 2005 p. 4; Schmidt et al. 2010).

The Need to Integrate Climate Change Adaptation into SEA in Nigeria

Nigeria has no legal or formal requirement for SEA; however, several developing countries and international organizations are rapidly adopting SEA as a decision-making support tool (Schmidt et al. 2005; OECD 2010; Sadler et al. 2011, p. 2). To better address the numerous environmental challenges such as climate change and environmental degradation in Nigeria, there is a need to supplement EIA with SEA. As climate change becomes a new challenge in planning, incorporating appropriate environmental assessment tool that can aid decision-making has become urgent. SEA is a very relevant tool in this context. “SEA provides a methodology not only for evaluating the impact of policies, plans and programs on the environment, but also for addressing the impact of environmental change on PPPs” (OECD 2009, p. 80). Practical examples documented by the OECD suggest that SEA is an appropriate and more rational environmental assessment tool for climate change adaptation. In order to fulfill the adaptation initiatives effectively, it is imperative to follow good practices. For example, the OECD has produced guidance for practitioners on how to apply and incorporate climate change adaptation within the SEA process (OECD 2006).

Furthermore, SEA being a flexible tool can be tailored to the local context or the specific strategic decision-making or planning process that it seeks to support. SEA can, therefore, serve as an assessment tool for both adaptation and mitigation purposes. In terms of mitigation SEA assesses the environmental effects of the plan in terms of potential emissions of greenhouse gases (GHG) that could be released from the plan and how to reduce them (Larsen and Kørnøv 2009; Larsen et al. 2012, p. 33). For example, any SEA of a development plan for a new urban area can include assessments of GHG emissions generated from traffic (Larsen et al. 2012, p. 33). On the other hand, Larsen and Kørnøv (2009) cited in

Larsen et al. (2012) envisage that adaptation considers climate change as an environmental problem of relevance to plan and if and how it is expedient to adapt the plan for future climate change. For example, the SEA of an overall spatial plan can include assessment of appropriate building sites in the light of future sea-level rise (Larsen et al. 2012, p. 33).

As stated earlier, countries and organizations are increasingly undertaking SEA, using formal or informal procedures (Sadler et al. 2011, p. 2). To the present authors' perspective, there are several reasons why SEA is increasingly adopted. Perhaps, the first reason is that SEA is widely recognized as being effective in integrating environmental protection measures in strategic decision-making. Secondly, several countries are creating activities geared towards sustainable development. SEA is an effective instrument for sustainable development (Albrecht 2011, p. 152). As pointed out earlier in the chapter, the purpose of SEA is to ensure that environmental considerations are taken into account and in order to inform high levels of decision-making, which facilitates assessments of policies, plans, and programs. Furthermore, SEA has the potential of improving PPPs, making sure that they take climate change issues into consideration, especially in countries with the legal provision for SEA (OECD 2009, p. 94). Another reason pointed out by Sadler et al. (2011) is that SEA serves as a lending and aid instrument used by donor agencies.

SEA is a multistage process that encompasses a spectrum of approaches and diverse arrangements, procedures, and methods (UNEP 2002, p. 493). Considering the diverse nature of climate-related impacts and adaptation issues in Nigeria, SEA is a structured planning tool to grind such hydra-headed challenges. An ideal SEA focuses on potential interrelations between concrete plans and programs and environmental changes by looking at the projected future of key socioeconomic variables, like trade patterns, commodity prices, population growth, migration flows while considering climate factors (OECD 2009, p. 80). The Nigerian national adaptation plan is geared towards strategic objectives comprising several sectors and ministries. SEA is better positioned to help improve relevant decisions towards achieving such integrated adaptation targets. According to the OECD (2009), an institution centered SEA approach may be best suited for mainstreaming climate change adaptation into national-level policy-making.

Moreover, in order to enhance national adaptive capacity, important environmental assessment tools should be in place as this will enable mainstreaming of climate change adaptation into sectoral policies. According to the IPCC "one way of increasing adaptive capacity is by introducing the consideration of climate change impacts in development planning, for example, by including adaptation measures in land-use planning, and infrastructure design or by including measures to reduce vulnerability in existing disaster risk reduction strategies" (IPCC 2007, p. 20; IPCC 2014, p.27). Furthermore, considering SEA in a regional land use development plan can enhance potentials for adaptation and make adaptation constraining decisions transparent (Helbron et al. 2011). In this light, quality of the regional plan-making weighting process is potentially improved (Helbron 2008). Climate change adaptation through SEA in Nigeria can be realized by following the existing relevant institutional arrangement and decision-making structures; however, therefore, the tiered approach is pertinent in order to avoid overlap with the existing EIA process. The definition of policy, plan, and program is given nevertheless. To be precise in relation to climate change adaptation in Nigeria, an example of a policy is the proposed National Policy on Climate Change while a plan is the National Adaptation Strategy and Plan of Action on Climate Change for Nigeria (NASPA-CCN). On the other hand, a program could be, for example, Climate Change Migration and Security Initiatives for Nigeria introduced within the Nigerian National Adaptation Plan.

New Strategic Programs That Need to be Integrated into SEA

Hence adaptation to climate change has become very necessary. Nigeria has established new strategic actions to be considered when implementing the national adaptation plan. This gesture is a milestone towards addressing the impacts of climate change ravaging several communities in the country. However, the national adaptation plan must be implemented in a sustainable manner. Adopting a guidance framework relevant for assessing environmental risk that may occur through adaptation actions is imperative. Such a framework would help in improving the integration of climate change consideration into PPPs relevant to carrying out robust adaptation strategies (OECD 2008a). Even though the proposed strategic programs are designed to reduce the impact of climate change on vulnerable communities in Nigeria and enhance adaptive capacity of the affected communities, SEA can be employed as an environmental assessment tool. In this context, SEA could help to make informed decisions so as to ensure that communities are not adversely affected after implementation of such strategic actions, at the same time, improving such adaptation strategies. It is worthwhile to keep in mind that "any adaptation action can create unintended impacts on other natural and social systems" (Adger et al. 2005, p. 81).

Some of these new strategic programs for adaptation to climate change provided in the National Adaptation Strategy and Plan of Action for climate change in Nigeria (NASPA-CCN 2011) include:

- Agricultural Extension Programs Services
- Integrated Water Resource Management Program (watershed and coastal)
- Community-based Natural Resources Management Program (forest sectors)
- Comprehensive Emergency Management Program
- Climate Change, Migration, and Security Initiative (e.g. Economic Development and Poverty Reduction Strategy).

Furthermore, implementation of the National Biodiversity Strategy and Action Plan (NBSAP) is a relevant aspect that needs to be considered in SEA. Hence, the need for action on climate change and biodiversity loss is firmly acknowledged as one of the new environmental challenges in Nigeria (NASPA-CCN 2011, p. 49; NEST 2011, p. 127). SEA is also required by Article 14, paragraph 2 of the Biodiversity Convention.

Benefits and Potential of SEA Within the Context of Climate Change Adaptation

Integration of climate change adaptation into SEA is relatively new particularly in those developing countries without formal requirement for SEA. However, in developing countries where SEA has become part of environmental assessment tool, it provides a ready entry point for climate change consideration in strategic decision-making at the sector level (OECD 2009, p. 101). "SEA as a decision-aiding instrument can contribute to the prevention of conflicts with a policy for adapting to climate change" (Helbron et al. 2011). According to OECD (2009) building climate change consideration into an SEA can help:

- To identify whether sectoral strategies are viable and sustainable under different climate scenarios. For example, in areas facing increasing water stress, SEA can help to assess different strategies for the reform of the agricultural sector with different water requirements to identify which strategy is most sustainable under different climate scenarios.
- To analyze whether a sectoral strategy might lead to increased vulnerability of the sector where natural and human systems are affected by climate change and thus prevent maladaptation.
- To identify which adaptation intervention can enhance the resilience of the sector in the face of climate change (OECD 2009, p. 101).

Potentials of SEA for Climate Change Adaptation in Nigeria

There are several benefits that could be associated with considering climate change adaptation in SEA. Most importantly, SEA application is imperative in meeting relevant policy commitments related to climate change in Nigeria. For example, SEA can help improve decision-making related to proposed adaptation programs of the Nigerian Ministry of Environment to achieve the objectives of NASPA-CCN by:

- Identifying policy, plans, and programs that are sensitive to climate change
- Incorporating stakeholders and public views at an early stage of planning
- Providing environmental-based evidence to support informed decisions
- Improving strategic actions (e.g., national and sectoral adaptation programs) and avoiding the risk of maladaptation
- Determining communities and socioeconomic groups that are increasingly vulnerable to climate change impacts
- Integrating environmental aspects that are often disregarded in sectoral plans, e.g., vulnerability to climate variability and change
- Evaluating the environmental impacts of adaptation strategies as well as possible conflicts with other existing regional or national plans and programs
- Addressing cumulative and synergistic effects which may lead to decisions that could prevent adverse consequences on urban and rural communities.

Conclusion

The present and future climatic changes in Nigeria could be very detrimental to ecosystems and vulnerable communities. Hence, the impacts of such climatic events have become inevitable. Climate change considerations should become part of policy-making and planning process in Nigeria. Adaptation is widely recognized by decision-makers as one of the effective measures to reduce the unavoidable impacts of the changing climate on the human environment. Given that Nigeria has initiated and designed a national adaptation plan with the aim of addressing the emerging climate change impacts across the country, it is also indispensable for a robust implementation of the national adaptation plan. While some progress has been made especially through establishing a National Adaptation Plan for Nigeria, a lot more remains to be done. It is, therefore, imperative to adopt a guidance framework for assessing several environmental risks which may improve the integration of climate change consideration into PPPs in order to make informed decisions and carry out robust adaptation strategies (OECD 2008b). SEA provides a structural approach to incorporating environmental considerations into PPPs at different levels, including sector level (OECD 2009, p. 185).

SEA can help to improve the adaptation programs laid in the national adaptation plan by bringing transparency in their implementation from the early stage of decision-making. SEA can help in improving adaptation programs as it allows for the participation of the public and relevant stakeholders, particularly at the early stage of the overall decision-making putting their suggestions into consideration and even strengthening the subsequent project-specific EIA. Flexibility is one of the characteristics of SEA. This assessment tool is not only a useful tool for climate change adaptation decision-making but also for making decisions related to climate change mitigation and poverty reduction strategies (PRS). However, following good practice climate change adaptation could be considered in the SEA/EIA framework. Adaptation to climate change is a crosscutting issue that needs to be addressed through integrated decision-making. SEA allows for a better cooperation between crosscutting environmental sectors. In this respect, regional environmental authorities have a key role to play in carrying out robust adaptation strategies. There is, therefore, a need for capacity building and training of relevant staff in SEA, EIA, and climate forecast. Training is very essential and crucial to take full advantage and to promote new skills. This would enable stakeholders and policy-makers to envisage the alternatives of future development and to apply the precautionary principle when necessary, so as to reduce climate risks. Therefore, an appropriate environmental assessment tool such as SEA can help spur robust decision-making regarding adaptation options in Nigeria.

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Sustaining Cooperation in the International Climate Change Regimes: Employing Game Theory and Network Theory

Joon-hyuk Chung

Contents

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Abstract

For decades, the leverage of transnational actors has skyrocketed, while still an international regime is crucial in managing climate change. Acknowledging this point, this chapter aims to find how to analyze the structure of climate change regimes, why international cooperation is hardly maintained in the regimes, and how to sustain it. To narrow the gap between theory and reality, this chapter integrates the game theory and the network theory. Game theory is used to analyze the negotiations in the regime, and network theory is widely applied to discuss the structure and interactions among diverse actors. The author verifies that the system inside the regime is still international, whereas outside the regime is similar to the network shape. Furthermore, the structure of the regime analyzed proves to be disadvantageous for sustaining cooperation. Thus, the author proposes practicable solution to sustaining cooperation by finding the actor who could fill the structural holes created in the regime. This chapter is one of the first to implement an interdisciplinary study merging game theory and network theory to deal with climate change regimes. This chapter might be helpful to the policy makers and scholars devising methods to improve the efficacy of regimes on managing climate change.

Keywords

Climate change • International regime • Metaphor of castle • Prisoner's dilemma • Tit-for-tat strategy • Stag hunt • Network • Structural hole • Post-developing country • Power division

Introduction

Since the 1970s, international regime has drawn attention from states as an effective tool for counteracting the effects of environmental problems (Young 1989). Regime is defined as "a set of explicit or implicit principles, norms, rules, and decision making procedures around which actor expectations converge in a given issue-area" (Krasner 1982, p. 186). As the demand for climate change regimes had also been proliferated, Rio Earth Summit declared to establish United Nations Framework Convention on Climate Change (UNFCCC), the first formal and legal international regime specialized in climate change, in 1992. From then on, international regimes have encouraged nations' responsible actions toward climate change.

To the contrary, still a great crux exists. In 2010 and 2011, the quantity of greenhouse gas (GHG) emission has rather swelled twice faster than the worst-case projections leading to 6 °C warming (Voorhar and Myllyvirta 2013). This insinuates that nations have made airy promises, which have barely been kept. To improve the efficacy of climate change regimes, this international practice of negligence ought to be ameliorated. With this perspective, two questions could be raised. First, why does the cooperation achieved in the period of resolution-making hardly sustain to the period of each state's practicing policies? Second, how could the international cooperation achieved by international regime sustain for a long period, without any state's defection?

Before answering to the questions, this chapter casts a cardinal question for the first: Why are international regimes still the crucial tool to manage climate change, in the more dynamically changed world system?

International Climate Change Regimes

Two mainstream international relations theories that have contributed to the discussion on the international regimes are realism and institutionalism. They have antithetic perspectives on the most roles of international regimes. However, there are some hypotheses about international regimes, on which both realists and institutionalists agree (Little 2011, p. 375).

1. States interact with each other in the anarchic international system.
2. States are rational and monolithic players.
3. States are the unit which is responsible for the formation of regimes.
4. Regimes are established based on mutual cooperation in the international system.
5. Regimes promote international orders.

These major hypotheses of regime theory were established in the twentieth century. However, from then on, many other transnational actors, such as international non-governmental organizations (INGOs), transnational corporations (TNCs), and epistemic community (which refers to the group of scholars), have grown as pivotal players in the world politics along with the globalization (Duffield 2001; Edwards and Gaventa 2001; Kahler 2009). Even some studies (Latour 1987; Kim 2011a) applied Actor–Network Theory (ANT) and suggested that the technologies also operate as a key actor in the world politics. That is to say, states are not the only actors in the world politics, and the international system has evolved into a more sophisticated system, which is unwieldy to be dealt with the only *international* political approaches. Given the rise of the transnational actors, the "states" in the hypotheses (1) and (2) would rather be understood as signifying *state governments*. This would facilitate explaining the presence of transnational actors, for it does not reckon the state per se as a unified actor (Willetts 2011, p. 413).

On the contrast, the international regimes still *thrive*. Then how could this be explained? First, path dependence could be one of the conceivable answers (Keohane 1984). When the international regimes were established, states legalized themselves to be the sole formal actors in those regimes. Even if the whole international system has transformed into more complicated ways, the dominant status of states inside the regime is still maintained by the inertia. Other transnational actors could merely have indirect clout on the decisions of regimes by lobbying or acting as facilitators. Thus, the states are the only de facto actors inside the international regimes.

Second, the regimes now simultaneously operate as a contrivance for states to preserve their vested rights against transnational actors. By monopolizing the role of decision-making, they conserve the status as the most authoritative actors in the regimes. Especially, given the fact that environment is a common-pool resource managed perfectly by states and that states retain the best capability to protect the environment (Barry and Eckersley 2005), the leverage of states in the international climate change regime is inapproachable. Due to this vantage of states, other transnational actors would hardly dominate the state (Shaw 2000).

This disjunction between the systems in and out of the regime could be easily explained by *the metaphor of castle* in Fig. 1. States have built a *castle* called international regime and maintain their ascendancy by disrupting other transnational actors' foray to directly participate in decision-making, with the *wall* of international regime. Understandably, states not only act inside the regime but also actively interact with other actors outside the regime.

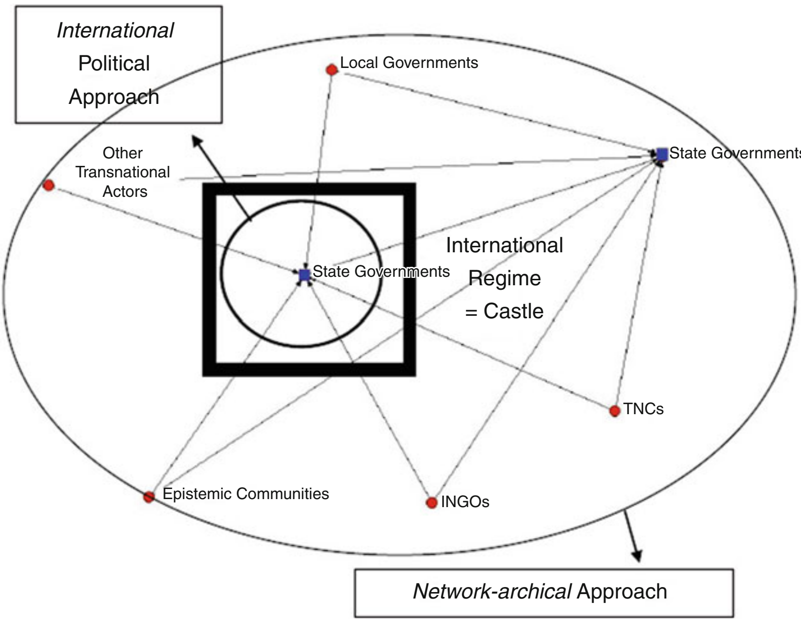

Fig. 1 The metaphor of castle

Thus, inside the regimes do states retain the clout, and the anarchic system persists. This implies that employing game theoretical approaches, which has been applied by the institutionalism, is still valid in analyzing the international regimes. This chapter employs a few elementary game theories: prisoner's dilemma and stag hunt.

First of all, the author would briefly explain what game theory is. Game theory could be defined as "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers" (Myerson 1991, p. 1). The components of game theory often considered to be essential are players, actions, information, iteration, and payoffs. *Players* are literally the actors of the game, the people, or parties participating in it. *Actions* are options that players could choose during the game, which is often divided into two, cooperation (C) and defection (D). *Information* provided for players before the game decides whether the game is *perfect*, which means the player knows what the other would choose if they choose a given action, and *complete*, which implies one knows the characteristics or strategies of the other. *Iteration* is about whether the game is repeated or merely one off. *Payoffs* are the results, which could be either benefits or damages, one receives from the game, depending on what himself/herself and the other chose (Kim 2013).

Prisoner's dilemma has been thoroughly particularized in the field of environmental economics to account for climate change negotiations (Barrett 2003; Decanio and Fremstad 2013; Finus 2001; Wood 2010). On the contrary, few have attempted to exploit the payoff structure of stag hunt (Endres and Ohl 2002). Game theories are expected to analyze what the real model of international regimes is and find out why current regime is insufficient for sustaining cooperation although some criticisms against adopting the model of Stag Hunt and Prisoner's Dilemma exist (Harrison 1983). Also, to elucidate the structure of the regimes more realistically and contain the oversimplification induced by the game theory (Haggard and Simmons 1987), this chapter employs a network theory in discussing some complex aspects of international regimes. Network theory, more precisely social network theory (SNT), is the theory essentially developed in the field of sociology, which is to systematically analyze relationships between individuals.

In dealing with the interactions between transnational actors outside the regimes, this chapter fully adopts network-archical approaches. Current world system is continuously transforming and restructuring through the polymorphous activities of transnational actors. Network theory is congenial to discuss this dynamic system, for it focuses on the interactions between actors and the structure itself and makes it possible to analyze relationships in various levels (Maoz 2010). Also a few studies have successfully employed the network theory to methodically apprehend the international environmental issues (Betsill and Bulkeley 2004). In specific, this chapter employs the perspective of SNT. Through social network analysis (SNA), which has recently been used in the field of sociology to analyze the social network between people by using software such as Ucinet 6.504 and NetDraw 2.137, this chapter tries to analyze the dynamic world politics related to climate change, finding some solutions to make effective resolutions in climate change regimes. This chapter also analyzes the relationship between actors with Ucinet 6.504 and NetDraw 2.137, acknowledging its efficacy verified in some studies (Kim 2011b). Still the author recognizes that the results from SNA could not be absolute, since the analysis of network through SNA is essentially rooted in the researcher's observation (Hanneman and Riddle 2005).

This chapter opts for UNFCCC as a subject matter, as "the UNFCCC continues to play an umbrella role and provides the framework for a number of essential functions, including serving as a legal setting, providing information, and constituting a forum for negotiations" (Keohane and Victor 2010, p. 21).

The Payoff Structure of Current UNFCCC: Prisoner's Dilemma

Ostensibly, UNFCCC seems to be an effective international regime, as it provides and contrives many methods to manage climate change. However, the total amount of emitted GHG has rather increased. This obvious growth of GHG emission negatives the efficiency of UNFCCC. Then, to figure out why current UNFCCC is of little efficacy, the structure of UNFCCC should be analyzed thoroughly. Thus, this chapter systematically analyzes it mainly harnessing the game theory, with supplementing some points through network theoretical approach.

Players

The total number of states currently (2013. 12.) participating in COP is 194. It seems at a glance that analyzing with N-person ($N > 2$) game theory is congruent, as the number of states is more than 2. However, every single state has diverse interests and objectives, due to the significant variances in the international relationship, impact of climate change that states confront, and energy reserve, etc. Due to this divergence of each state's goal, analyzing the game of UNFCCC with N-person game would not be appropriate. N-person game might exceedingly simplify the intricate relationship of parties' interests. Rather, it is desirable to grasp the game of UNFCCC as a *complex of 2-person games*, which is associated with various interests of states. Given states forge linkages with others through the games, the complex could be represented as a complicated network in Fig. 2.

After establishing this network with each other, states discerned that there are some kindred states whose opinions are similar to themselves. As a result, through many times of UNFCCC meetings, states have gradually established coalitions (Shin 2011) as shown in Fig. 3.

The classification of the coalitions is majorly based on the standard stated in the UNFCCC homepage (UNFCCC n.d.). Those coalitions have been the de facto players in the COP. Brief recitation for key stances of each group is stated below.

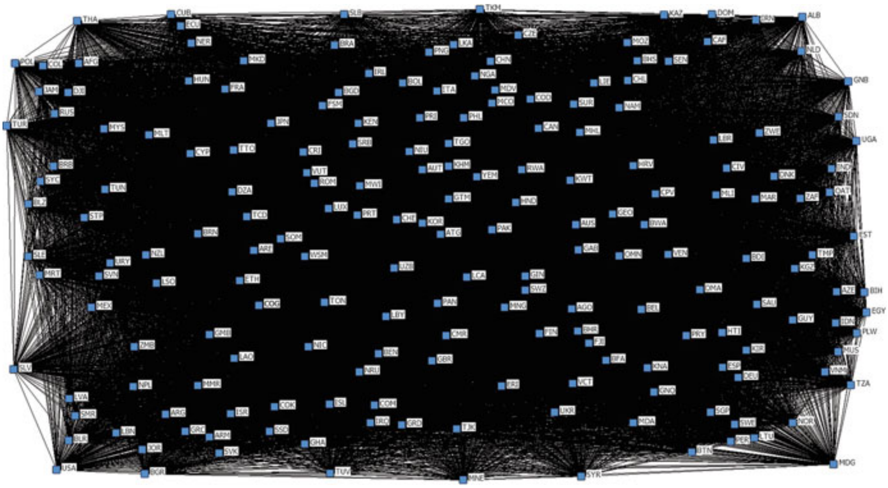

Fig. 2 Two-person game network of parties in UNFCCC

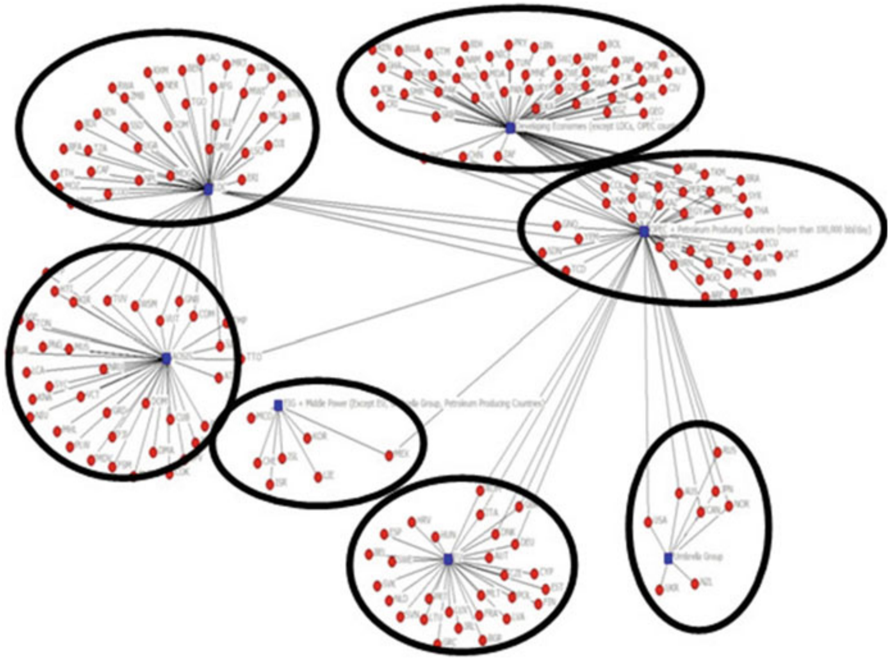

Fig. 3 Coalition building in UNFCCC

LDC (Least Developed Countries)

LDC is a group of nations designated by the United Nations as the most impoverished countries. They are indebted to many developed nations, and those debts are unaffordable. Due to their chronic poverty, they are susceptible to the climate change impacts. Especially, as most of them are located near the equator or deserts, where natural disasters frequently strike, their capacity of climate change adaptation is significantly weak.

OPEC + Petroleum-Exporting Countries (More Than 100,000 bbl/day)

OPEC member countries mainly assert that if states are to regulate the quantity of oil usage to dwindle GHG emission, their economy would be severely damaged. They also have pressed for compensation for the reduction in using petroleum and intentionally disturbed the passage of effective resolutions. Rather, they are more interested in developing clean technologies and carbon capture and storage technologies. Since their major exporting items are crude oil and associated by-products, the chance of their converting stance is scarce (Fig. 4).

Huge petroleum exporting countries are also prudent in agreeing on GHG emission reduction, since exporting an oil has been a major source of their incomes. However, as they retain other industries to substitute it or they exert themselves to expand other industries, their opposition to GHG emission reduction is not so serious as that of OPEC member nations.

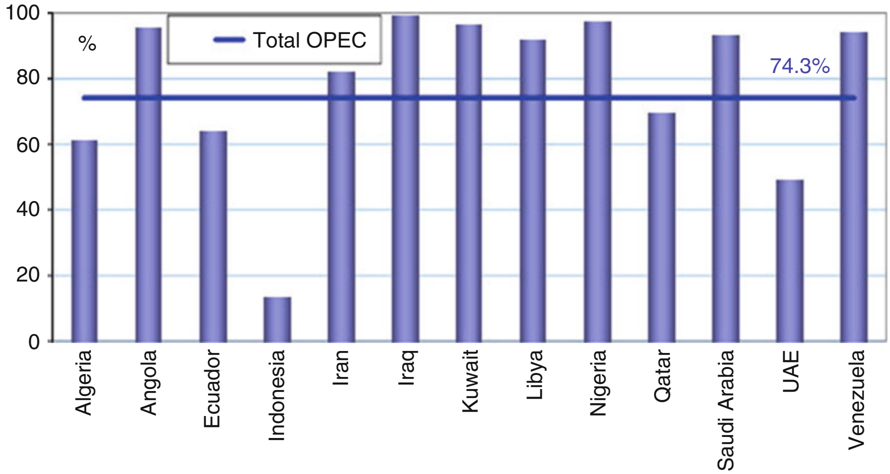

Fig. 4 OPEC member countries' dependence on fossil fuel export in 2008 (Korean Ministry of Foreign Affairs 2010). *Vertical axis: fossil fuel export-to-total export ratio (%)

Developing Economies

Developing economies are represented by China and India. These two mogul states recently give an eye to environmentally friendly industries, including alternative energies. They traditionally stressed the principle of Common But Differentiated Responsibility (CBDR), which is to induce more active supports of developed nations for their sustainable development.

AOSIS (Alliance of Small Island States)

Small island states are in the peril of losing territory and even their whole countries, due to the global warming and consequent rise of sea level. They desperately need the international cooperation to protect their living foundation. Unless the situation hectoring their right to live is completely ameliorated, their stance would be immutable. They clamor for the responsible and effective actions from the whole states to restrain GHG emissions.

EIG (Environmental Integrity Group)

EIG is a group of middle power countries, which are not incorporated in other groups, such as Mexico, Korea (Rep. of), and Switzerland. They aim to mediate between developed nations and developing nations, partially to make constructive plans to manage climate change and partially to hold a leadership in the climate change regime. One of their most remarkable achievements was the establishment of NAMA (Nationally Appropriate Mitigation Actions) Registry, suggested by Korea. It was to encourage the GHG emission reduction and sustainable development of developing economies, by letting them voluntarily construct the mitigation projects and providing the support of developed nations depending on their efforts.

EU (Europe Union)

EU has long been the leading group in the climate change regime. They have acknowledged their own responsibility for climate change and tried to make effective results to mitigate climate change. However, although EU has achieved notable strides in the negotiation, some express concerns on the future of EU's leadership (Obertür and Kelly 2008). Also, lately, the emission trade market of EU has significantly declined both in its size and influence.

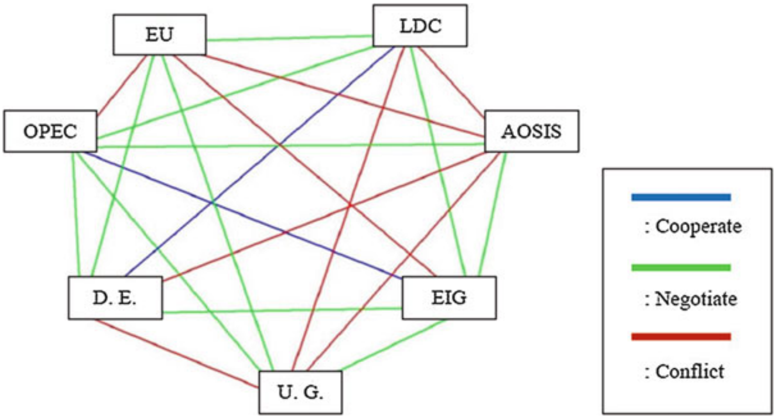

Fig. 5 Network of GHG emission reduction game

Umbrella Group

The Umbrella Group is not a cohesive coalition built with strong fellowship or common interests. Component states, such as the USA, Japan, and Russian Federation, separately try to take the hegemony in the climate change regime. Also, some states constituting this group, such as the Russian Federation, Canada, and New Zealand, are expected to favor with the climate change later (Globalagriculture 2012). This is part of the reason they are not proactive in GHG reduction emission and climate change mitigation.

Synthesis

As UNFCCC majorly pursues climate change mitigation through restricting GHG emissions, players have bickered mostly about whom and how to reduce GHG emissions. It could be called a *GHG Emission Reduction Game*. From now on, this chapter concentrates on this game of UNFCCC. It is the only game that the entire players participate in and could be measured as twenty-one dissimilar 2-person games between coalition groups. The comprehensive frame concerning these twenty-one games is a North–South problem. Thus, the discussion on GHG Emission Reduction Game in this chapter would essentially focus on the altercations related to the North–South problem. This provokes the serious opposition between Developing Economies, LDC, and EU, Umbrella Group. In most conflicts in UNFCCC until now, EU has mediated through its own concession, following the principle of CBDR. This has been the staunch ground for the legitimacy of EU holding the leadership.

Considering the current status of UNFCCC, Fig. 5 shows the game network between coalitions. The relationship between coalitions this chapter discusses is restricted to the climate change issues. For instance, although OPEC and EU are in conflict on climate change issues, they could cooperate in other fields such as economy or security.

Information

UNFCCC is fundamentally an international regime, and thus it curtails the transaction cost and asymmetry of information among nations (Keohane 1984). In doing so, information about one state's climate change policies or favored strategies would have been apprehended by other states. As the nations have communicated with each other at the UNFCCC for 19 times until now, they definitely have understood and accumulated empirical information about other countries' policy preference. In this case, the game could be categorized into *perfect and complete* information game.

Iteration

An international climate change problem accompanies *irreversible* damage, which could not be perfectly restored. Although its major agenda could be changed as time moves on, UNFCCC would not be easily disbanded. This implies that the game of UNFCCC would be iterated *infinitely*, unless the other apparatus is seriously needed.

In specific, considering the role of UNFCCC and COP, two phases are infinitely repeated during the process of the GHG Emission Reduction Game: phase (1) planning (setting GHG emission reduction goals such as predicted amount of reduction, deadline for achieving the reduction goals, etc.) and phase (2) practicing (implementing actual policies for fulfilling the planned goals such as emission trading or carbon tax, etc.). If the players fail to build an effective and realistic plan, players would renegotiate about the plan and redeem it. In this case, the game could not proceed to the next phase, and keeps abiding on the phase 1. During the procrastination in making effective plans, states often take quite extemporaneous or perfunctory measures. If the players successfully devise an effective and realistic plan, they proceed to the next phase, fulfilling the promise stipulated in the resolutions. This cycle of phase 1 and 2 would indefinitely ingeminate as climate change problem could not be perfectly resolved. Figure 6 shows the iteration of two phases and what exactly *sustaining the cooperation* means. Sustaining the cooperation means the situation where players keep choosing C and endeavoring to cope with the climate change. The mutual cooperation should sequentially occur in phase 1 and 2 to consummate the whole process with efficacy.

Actions

Actions that players could choose in the game theory are comprehensively classified into cooperate (C) and defect (D). In the GHG Emission Reduction Game of UNFCCC, C is to cooperate for managing the climate change problem and D is to neglect the indispensability of managing the climate change, implementing makeshift policies. In specific, international cooperation connotes that every player in the

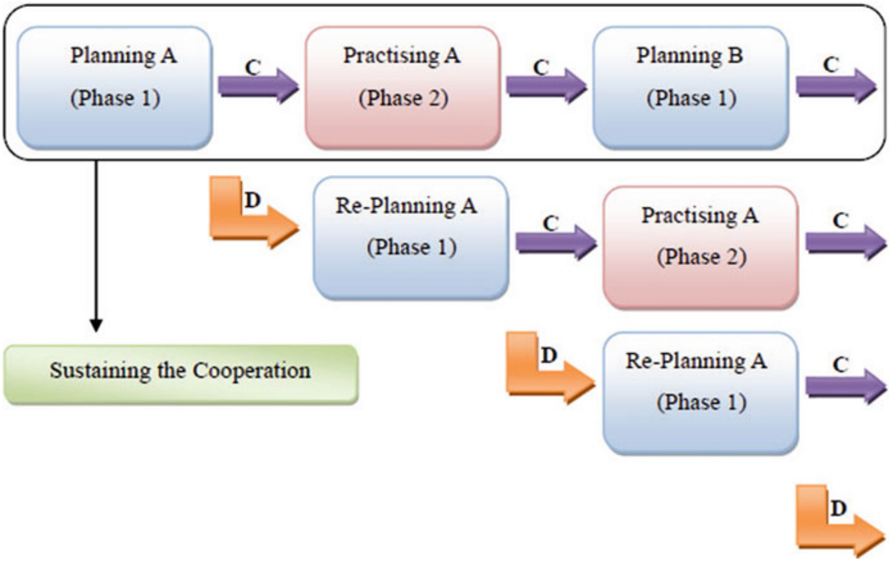

Fig. 6 Iteration model of UNFCCC game

Table 1 Results of choosing C and D in each phase of GHG emission reduction game

C	Phase 1	Producing an effective and realistic mitigation/adaptation plan
	Phase 2	Making an effective and realistic efforts to fulfill the plan
D	Phase 1	Exercising a veto on an effective and realistic plan or producing an abstract and perfunctory plan
	Phase 2	Neglecting the duty stipulated in the plan or implementing perfunctory countermeasures for the plan

game yields their self-interest to some extent, which is usually economic interests. States which choose to cooperate should bear the burden of managing the global common-pool resource. Therefore, strictly speaking, agreements made by one player's unilateral concession could not be called as a result of international cooperation. Table 1 shows the results of choosing C and D in each phase.

Outcome and Payoff

Given the characteristic of climate as a common-pool resource, theoretically players could secure the biggest interest when they unilaterally defect (DC) in the GHG Emission Reduction Game. In this case, the player who defected could obtain profit from economically developing and receiving *boons* from another player's effort of protecting the environment. This is called a free riding, which could generate social dilemma of inequity (Olson 1971). And these egoistic behaviors result in the tragedy of commons, which is consequently prejudicial to everyone (Hardin 1968).

Table 2 Payoff structure of prisoner's dilemma

	C	D
C	3,3	0,5
D	5,0	1,1

When putting climate into the category of national interest, it could fall under the purview of *long-term* interest. The profit states could acquire from mitigating the climate change is not quantitatively measurable in a short period of time. This characteristic of the climate as an economic good would be referential to the concept of *the shadow of the future* (Oye 1986) in the game theory. For nations to value the climate change issues more than now they do, the shadow of the future for managing climate change problems has to be lengthened.

Next-best payoff could be achieved by mutual cooperation (CC). To cooperate with each other, players have to abandon some of their short-term interests by investing in the long-term interest. In doing so, players could effectively cope with climate change and guarantee a secure future.

Third-best choice is mutual defection (DD). By defecting each other, players could strive to economy or national security issues. However, the time keeps moving on and the quantity of irreversible damage would be swelled apace. This possibly would provide short-term benefits of economic development or advanced security which players value the most, but the natural environment would cause grave problems in the near future.

The worst payoff for players is the case of CD, achieved by unilateral cooperation. In this case, the player who chose C turns out to have beaten the air. However much effort the player made to manage climate change, the other player would keep emitting GHG, resulting in the efforts of the player who chose C become profitless.

Therefore, the preference ordering of the game is DC > CC > DD > CD. This implies that the payoff structure could be best explained by *prisoner's dilemma*. Table 2 is the generic payoff structure of prisoner's dilemma. The numbers in Table 2 are not used to signify specific features, but to simply represent the relative size of payoffs.

Synthesizing Aspects of the Game

When aggregating all the aspects mentioned above, the payoff structure of the GHG Emission Reduction Game is *infinitely iterated 2-person prisoner's dilemma*.

In the most cases of prisoner's dilemma (PD), the payoff results in DD. This is because a rational player chooses D, for D is a strictly dominant strategy, which could provide the highest payoff to the player. Also, it is a common knowledge that the other player is also rational and would choose D. Considering this, DD becomes the dominance solvable, as it is the only rationalizable strategy. Here the Nash equilibrium, the payoff with no incentive for both players to change their actions (C or D) and reached by the best response to the other player's choice (Nash 1951), is established in DD. Thus, repeated PD itself has a characteristic of terminating in infinite DD (Kim 2013).

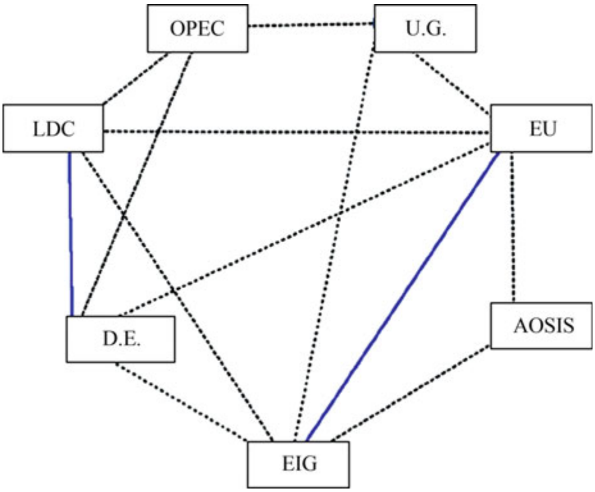

Fig. 7 The dissolution of network between coalitions in GHG emission reduction game

If the situation of DD is iterated in aeternum, what would happen to the game network? To answer this question, this chapter applies the concept of *closeness*, which is one of the most representatively exploited concepts when examining the centrality of nodes in the social network theory (Freeman 1979). Closeness is about the distance between the nodes. The concept of closeness is often restricted to the physical distance when analyzing the structure of societies. However, the distance between actors could also represent the *psychological distance* in the game network of UNFCCC, for players decide to choose C or D by anticipating what the other player would choose in the iterated game, and that process of determining is a mental work, where reputation becomes of importance (Mailath and Samuelson 2006). If players keep choosing D, the distance between them might be elongated. The GHG Emission Reduction Game would end in the dissolution of linkages between players in conflict and debilitation of linkages between players once negotiated as represented in Fig. 7 (conflict: blank, negotiate: dotted, cooperate: solid).

As shown in the Fig. 7, the cohesive game network would become a loose network with many *structural holes*. Through 19 regular meetings of COP, the network between coalition groups has been metamorphosing into the type in Fig. 7. Although states periodically congregate to take measures against climate change, they are mostly disappointed with each other and merely pursue their own interests. If the entire game network were to be imploded in the end, the climate change regime per se would also become obsolete.

Thus, in order to make effective and realistic measures, it is crucial to end the iteration of DD (in the game theoretical approach), which means to bridge the structural holes (in the network theoretical approach). In the next section, this chapter examines the possibility of ending an iterated DD by using tit-for-tat strategy in the PD of the GHG Emission Reduction Game.

Sustaining International Cooperation with Tit-For-Tat Strategy: Is It Possible?

Tit-For-Tat Strategy

Tit-for-tat (TFT) first received a widespread attention after having been introduced in *The Evolution of Cooperation* (Axelrod 2006). TFT program constructed by Anatol Rapoport won the first place in the computer tournament Axelrod held. TFT first chose C and then follows what the other player chose at the previous period. TFT never scored better than others in the specific period of game, as it allows them to defect. However, TFT induced other players to pursue mutual cooperation by letting them perceive the game to be nonzero sum, and as a result, it became a winner in the end.

From the success of TFT, Axelrod (2006) suggests players practice "reciprocity" (pp 136–139). By maintaining the equipoise between the cooperation and retaliation phase, and never defecting first, the simplest strategy of TFT could promote the possibility of mutual cooperation (CC). Acknowledging that TFT is the best to promote cooperation in PD, this chapter examines what the result would be when (1) one player (unilateral) and (2) both players use (bilateral) TFT strategy in the game of climate change.

Limitations of Using TFT Strategy

It is undoubtedly explicit that TFT generates CC better than any other strategy in PD. However, when a player unilaterally uses TFT strategy, it also has a limitation. Axelrod (2006) also states, "The trouble with TIT FOR TAT is that once a feud gets started, it can continue indefinitely" (p. 138). This is a significant disadvantage of TFT in dealing with climate change, now that it would be laborious to sustain international cooperation by using TFT strategy.

First, this chapter takes cases where player 1 uses TFT and player 2 uses (1) nasty and (2) alternation strategy to illustrate the possible quandary induced by the unilateral TFT strategy. Nasty strategy is to choose D for every period of the iterated game. In this case, feud might be perpetuated, since TFT would follow D which nasty always chooses. By doing so, coalition groups could not achieve any further cooperation. Rather, the situation ends with the unremitting DD, which means that the players immerse themselves in managing their short-term benefits, especially the economic development (Fig. 8).

Next, alternation strategy is to choose C at the odd number period and choose D at the even number period. In this case, using TFT would result in the endless iteration of CD and DC. The revealing point is that player 1 always cooperates in an even number phase (except for CC at the first period) and player 2 always cooperates in an odd number phase. As players both choose C in the first period, they could draw a specific resolution. However, in the next period, which is phase 2 (practicing), player 2 chose D, neglecting the duties stipulated in the agreed resolution.

Player 1: C → D → D → D → D → D → D → D ...

Player 2: D → D → D → D → D → D → D → D ...

Fig. 8 TFT versus nasty strategy – perpetuated defection

Player 1: C → C → D → C → D → C → D → C ... → D → D → D ...

Player 2: C → D → C → D → C → D → C → D ... → D → D → D ...

Fig. 9 TFT versus alternation – iteration of CD and DC

To punish this negligence, player 1 chose D in the third period, which is again phase 1 (planning). By doing so, players could not set specific goals of effectively responding to climate change. Then again player 2 and player 1 alternately defect each other. This would not induce effective and realistic measures against climate change (incurring infinitely iterated phase 1) and the mutual cooperation would never be achieved. Eventually, this would end in the perpetuated DD. Rational players would realize it is not of assistance to choose C in case where the other player would certainly choose D. In other words, there is no incentive for players to choose C in the iterated CD and DC. Thus, a rational player would forsake choosing C and adopt the nasty strategy (Fig. 9).

During the successive vicious cycle of defection, the quantity of irreversible damage would uprise as time goes by. If players do not cooperate until the quantity of irreversible damage reaches the point where climate change catastrophe would inevitably occur, there would be no alternative to manage the problem. Understandably, by adopting some strategies such as nice strategy (always choose C), CC could be achieved in the case of unilateral TFT. However, it is a handful of exceptions, which is almost infeasible in the international world. In most cases, where players try to choose D to get more outcome, CC would not be achieved whatsoever. Adopting a unilateral TFT could not completely solve the problem of sustaining international cooperation.

Second, although both players use TFT strategy, sustaining cooperation is not always practicable. To sustain CC, Nash equilibrium has to be formed in CC. In the infinitely iterated game, how much the players value the shadow of the future is to be analyzed. To measure the shadow of the future, the value of future payoff should be converted into the value of current payoff. The average of converted future payoff's value in each period is called discounted average payoff (Kim 2013). Figure 10 shows how to find the discounted average payoff.

First, the discounted average payoff of choosing C (v_c) when both players are using TFT strategy could be evaluated, based on the structure of PD in Table 2, as below:

$$v_c = (1-\delta)\left(3 + 3\delta + 3\delta^2 + \cdots\right) = (1-\delta)\cdot\left(\frac{3}{1-\delta}\right) = 3$$

Discounted Average Payoff v

$$= (1-\delta)(u_1 + \delta u_2 + \delta^2 u_3 + \cdots + \delta^{t-1} u_t + \cdots)$$

$$= (1-\delta)\sum_{t=1}^{\infty} \delta^{t-1} u_t$$

$$(u_t = \text{payoff acquired at the period t},$$

$$\delta = \text{discount factor},\ 0 < \delta < 1,\ \delta \equiv \frac{1}{1+r},\ r = \text{discount rate})$$

Fig. 10 Evaluation of discounted average payoff

From the period t,

Player 1: D → C → D → C → D → C → D → C ...

Player 2: C → D → C → D → C → D → C → D ...

Fig. 11 TFT versus TFT after player 1 first chose D

Next, to find the discounted average payoff of choosing D (v_d), this chapter hypothesizes that player 1 chose D at the period t. Then player 2 would punish it by choosing D at the period (t + 1). This cycle of DC and CD will be infinitely iterated (Fig. 11).

In the indefinite iteration of DC and CD, a player receives 5 in the period of DC and 0 in the period of CD. Thus, the discounted average payoff of choosing D (v_d) is

$$v_d = (1-\delta)\left(5 + 0\cdot\delta + 5\delta^2 + 0\cdot\delta^3 + \cdots\right) = (1-\delta)\cdot\left(\frac{5}{1-\delta^2}\right) = \frac{5}{1+\delta}$$

Last, to establish a Nash equilibrium in CC, v_c should be bigger than v_d ($v_c > v_d$):

$$(v_c > v_d) = \left(3 > \frac{5}{1+\delta}\right) = (\delta > 0.66)$$

This implies that bilateral TFT not always maintain a mutual cooperation. Also, sustaining a CC with bilateral TFT requires players to rate the future payoff monumentally high ($\delta > 0.66$). However, realistically, long-term behoof of managing climate change problem could not be more valued than economy or national security, directly pertaining to the everyday survival of nations. Also, as the payoff from DC is bigger than that from CC, it is exacting to concern to managing long-term interests. This difficulty in recognizing the value of long-term interests makes it almost impossible to take care of the climate change problem.

It is an unquestionable truth that TFT could promote the possibility of cooperation. However, the game of UNFCCC is constituted of two different phases. If one of them results in DD, DC, or CD, the other phases where CC was achieved also become profitless, as phase 1 and 2 compose a uniform process of effective response to climate change.

Radical Change Is Needed

The key reason TFT could not readily sustain the cooperation is that the payoff from DC (5) is bigger than from CC (3). In other words, although CC is achieved at one period, still an incentive to choose D remains mighty. Technically speaking, this is not the problem of TFT. Instead, it is an essential problem that PD has. With TFT, the payoff structure of PD could not be hypostatically ameliorated. TFT could only promote the possibility of cooperation in the iterated game. Thus, the game structure of UNFCCC needs a *radical* change.

The radical change means the transformation between the first and second preference order as CC > DC. The most well-known structure that satisfies this condition is a *stag hunt*. In the next chapter, this chapter explores the structure of stag hunt (SH) as a substitute for PD and ultimately how it could sustain the international cooperation. The analysis of SH not only takes theoretical approaches but also proposes some realistic methods to change the payoff structure from PD to SH.

Stag Hunt as an Alternative to Prisoner's Dilemma

Stag Hunt

The stag hunt game structure was derived from a fable stated in *A Discourse Upon the Origin and the Foundation of the Inequality Among Mankind* (Rousseau 1755). Hunters are gathered to hunt a deer. Then, suddenly the hare appears near the hunters. Here, Rousseau set some conditions. A hunter could not capture a deer by oneself, for it is very fast. The possibility of successfully hunting a stag scales as the number of hunters hunting a stag increases. A hunter could readily catch a hare, regardless of what the other hunters do. However if one catches a hare, the other hunters indispensably could not catch a stag. Also, the value of a hare is less than that of a stag divided into N (the number of hunters).

In this game structure two problems occur in achieving cooperation. First, the problem of *uncertainty*. Although all hunters cooperate to catch a deer, it is not of certainty whether the hunters could hunt it. Only the possibility of successful stag-hunting increases. This could make hunters encounter a dilemma about which to hunt. Second, the problem of *mutual distrust*. Hunters do not know what the others would choose to hunt. Each hunter distresses oneself about the possibility of other hunters' catching a hare, while oneself chooses a stag.

These problems become the main obstacles that make choosing to catch a stag quite risky. If at least one hunter among the hunters chooses a hare, the other players who choose a stag would gain absolutely nothing.

Table 3 Payoff structure of stag hunt

	C	D
C	v,v	0,1
D	1,0	1,1

$v > 1$

Nevertheless, this chapter suggests to transform into *infinitely iterated 2-person stag hunt*. Every other factor of the payoff structure is unchanged, except for the payoffs. In this structure, the preference order of payoffs could be CC > DC > DD > CD, as a stag divided into N is more invaluable than a hare. As a result, mutual cooperation (CC) is more worthy than unilateral defection (DC). This makes a plethora of changes in the choice of players (Table 3).

As the game is constantly repeated, the players (or the hunters) would to some degree discern what each other would choose at the next period. This could help resolve the problem of mutual distrust. In the iterated games, rational players choose the best response to the other player's choice. If the other player is expected to choose a stag, oneself would rather choose a stag and vice versa. There is no incentive for players to choose a stag, when the other player is choosing a hare. It would lead to the outcome of 0. In this case, the Nash equilibrium is formed in CC and DD (Skyrms 2003). This means the iterated SH could beget the sustenance of cooperation or the sustenance of defection.

In addition, the iteration of game could solve the problem of uncertainty. If the mutual cooperation (CC) is eternally iterated, players could share the information and contrive improved methods to catch a stag. This could naturally diminish the uncertainty in catching a stag. However, this could be only resulted from an iteration of CC. Then among the two possible Nash equilibriums (CC and DD), which payoff would be realized?

The answer could be found by employing the concept of payoff dominance and risk dominance (Harsanyi and Selten 1988). Payoff-dominant Nash equilibrium refers to the Nash equilibrium which is Pareto optimal (Pareto efficient) among two or more Nash equilibriums in one payoff structure. In other words, if players choose to deviate from the payoff-dominant Nash equilibrium, one or more players would suffer a loss. In the SH structure, the outcome of catching a stag is always absolutely bigger than that of catching a hare ($v > 1$). Thus, CC is the payoff-dominant Nash equilibrium, and choosing C is a strictly dominant strategy, which could lead to the maximum outcome.

Still, the payoff dominance does not guarantee the realization and sustenance of CC. Risk dominance should also be considered. Risk-dominant payoff is the payoff which is more worthy to take a risk for choosing than the other one. Although $v > 1$, if the value of v is too small (e.g., 1.0001), selecting C becomes a risky choice. It is because hunting a stag when the other player is choosing a hare could result in receiving 0, while hunting a hare always guarantees a payoff of 1 (Kim 2013). Then when could hunting a stag risk dominates hunting a hare? To answer to this question, this chapter compares the risk factor of choosing a stag and a hare. To calculate the risk factor, suppose p is the probability of the player 2 to choose a stag. Then the outcome player 1 could earn from choosing a stag (C) is $p \cdot v + (1 - p) \cdot 0 = pv$ and from choosing a hare (D) is $p \cdot 1 + (1 - p) \cdot 1 = 1$. The risk factor for choosing a stag is the value of p which makes two outcomes of catching a stag and a hare equal. It is $1/v$. Also, the risk factor for D is the value of $(1 - p)$ which makes two outcomes equal. It is $(v - 1)/v$. Last, the risk-dominant payoff is the payoff with the less risk factor. Hence, for CC to be less risky than DD, v should be

$$\frac{1}{v} < \frac{v-1}{v} \Rightarrow 1 < v - 1\ (\because v > 1) \Rightarrow\ v > 2$$

However, in fact, risk dominance problem is not a big obstacle in sustaining cooperation in the iterated game. In the repeated game, the best response is to choose what the other player frequently selects. In this case, the dilemma of risk dominance is naturally diminished, since what the other player would choose becomes obvious as time goes by. Also, due to the payoff dominance of choosing a stag, the possibility of rational players' choosing a stag is far higher than choosing a hare. Hence, if players rationally seek for a bigger payoff and choose C, the situation of CC would be achieved. Then, players would keep choosing C through the iteration process, for they could predict that the other player would also choose C. At this point, due to the iteration, the problem of mutual distrust and the risk dominance becomes nothing to consider.

As the payoff of CC is bigger than DC, there is no incentive for rational players to choose D when cooperation is on the way. This is the supremacy of the SH structure per se against the PD. In the PD structure, although a mutual cooperation is achieved, an incentive to defect always presents. If the payoff earned from the mutual cooperation is the biggest, rational players would not try to defect. Therefore, the solution to sustaining international cooperation is a transformation of the payoff structure from PD to SH.

How to Change Into SH

Changing a payoff structure means to change the value of payoffs which comprise the structure. A transformation from PD to SH requires a change in the ordering between CC and DC. In other words, (1) the benefit received from choosing C should be increased or (2) the disadvantage received from choosing D should be strengthened.

However, strengthening the disadvantage of defection is treacherous. International climate change regimes, including UNFCCC, have a *binding* power, while they do not hold a *coercive* power. Even if UNFCCC could warn the parties which neglect their duties, it is mostly restricted *to psychological burdens* and a little amount of *taint on their escutcheons*. Especially, as most states themselves do not zealously endeavor to manage climate change, they seldom castigate other nations' negligence. In this circumstance, reinforcing an economic sanction against states which choose defection could even make states resign from the UNFCCC.

Realistically, it is also difficult to increase the absolute payoff of cooperation in the game. The cooperation in this case means to put national interests little aside and concern about global public interests. However, in the real world, the absolute value of protecting the environment could not be higher than that of the daily livelihood. The absolute benefit associated with daily living is more material to state governments than that of global public interests. States would hardly value the environment higher than the economy and national security, unless the quantity of irreversible damage crosses the Rubicon.

At this point, game theoretical approach could not give us a clear solution. As an alternative, this chapter employs the network theory. The iteration of DD in PD means the formation of structural holes in the network theory. Likewise, the change into SH, which encourages CC, could be interpreted as filling in the structural holes in the network theory.

However, all coalition players of the UNFCCC game pursue their own interests, and those rational players do not have any incentive to bridge the structural holes to sustain the cooperation. Therefore, an adequate actor could not be found in the level of coalition groups, and instead it would be discovered from the level of discrete state governments constituting the coalitions. Still, some incentive should be provided for each state to take mediating roles.

The incentive for the states could be the *leadership*. Currently, it is of certainty that some states in coalition groups, such as EU, Umbrella Group, EIG, and Developing Economies, vie for the initiative in UNFCCC so as to improve their soft power (Shin 2011). However, as they already belong to one coalition group, they inevitably reflect the major stances of the groups they belong to. The exceptions are the states of Umbrella Group, which is somewhat loose. However, it is doubtful that they could truly arbitrate between different opinions from, generally, developed nations and developing nations, for they have not experienced the circumstances of developing countries.

This implies that regrouping is necessary so as to forge a new group of countries that could mediate between the existing groups. Some middle power countries scattered in each group would be suitable for building a new coalition group and interceding between other groups. Some studies maintain that middle powers are "more responsive to humanitarian values than most, particularly larger states" (Black and Smith 1993, p. 763) and they have played a role as a mediator for a long time in other fields (Holmes 1965). In specific, the new group should consist of middle power, which underwent the experience of being a developing country. Middle power countries which are still classified as developing nations by IMF would not be appropriate, since they could not comprehend the stance of developed nations. Additionally, to ensure the active intercession with unwavering objective, the states' economy should not resort heavily to producing or exporting fossil fuels.

Some representative states that satisfy these all conditions are Singapore and Korea (Rep. of) from the Four Asian Tigers, and Czech Republic from countries recently joined EU. The appellation of the group that binds them into one could be

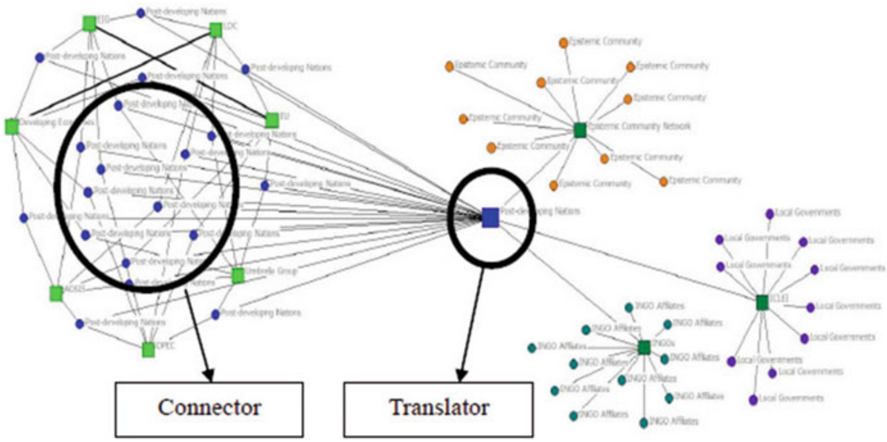

Fig. 12 Post-developing countries as a connector and translator

called *post-developing countries*. This is to emphasize the distinct characteristic these countries have, the transition from developing nation to developed nation.

The only problem left is that the post-developing countries do not have enough political leverage to play a role as a *connector*, who reconstructs the broken linkages in the same level of network. Some studies suggest that middle powers have to obtain support from other international actors to take international leadership (Yamasaki 2009). Thus, given that post-developing countries are originally categorized as middle powers, it would be helpful for them to tighten solidarity with transnational actors, such as INGOs, local governments, and epistemic communities, by working as a *translator*. Especially as INGOs per se have a form of transnational advocacy network (Keck and Sikkink 1998) and local governments have established their own network called ICLEI, post-developing countries could create a cohesive synergy effect when forming a network with those networked actors. Moreover, INGOs or epistemic communities could provide eclectic policy options that could embrace the opinions of multiple coalitions (Raustiala 1997) for the post-developing countries.

Translator links the nodes in the different levels, conveys the flow of meaning, and makes the meaning compatible so that the nodes could assimilate it (Kim 2011a). By operating as a translator connecting the transnational actors outside the regime to the state governments inside the regime, the post-developing countries could hold a high *degree centrality and betweenness centrality* (Freeman 1979), as shown in the Fig. 12.

Through this process, the post-developing countries group is expected to consolidate the leverage in the UNFCCC and ultimately act as a catalyst for sustaining the cooperation among states. Then the regime would operate more effectively and the transnational actors would more dynamically and actively participate in the regime.

Conclusion

This chapter started with raising three major questions and endeavored to find the answers. By applying the game theory and network theory, and sectionalizing the international system into *in* and *out* of the regime, this chapter was able to find to some extent realistic answers.

1. *Why international regimes are still the crucial tool to manage climate change, in the more dynamically changed world system?*

   States have path dependence on the regimes, and they effectively harness regimes to maintain their ascendancy in the international world. This results in the rearing up of transnational actors outside the regime, and the state's insistent dominance inside the regime.
2. *Why does the cooperation achieved in the period of resolution-making hardly sustain to the period of each state's practicing policies?*

   According to the game theoretical analysis, the payoff structure of games constituting the 2-person game network of UNFCCC is PD. Due to the *intrinsic-inferiority* of the PD in sustaining the cooperation, the game of UNFCCC has gotten bogged in a quagmire of ethereal DD, which means creation of structural holes in the network theory.
3. *How could the international cooperation achieved by international regime sustain for a long period, without any state's defection?*

   As the best strategy of TFT could not essentially solve the problem of PD, the radical change into *intrinsically superior* SH is needed, by filling in the structural holes. The role of doing so could be performed by the post-developing countries, through operating as a connector in the regime and translator out of the regime and establishing a staunch network.

   Some studies (Kim 2010; Ha and Kim 2010) argue that the rise of transnational actors would lead to the power shift or power transformation in the international system. However, the analysis on the international regime verifies that the states still own a *castle* that could protect their dominance. Thus, power shift would hardly occur until at least the near future, and rather the expected change could be called a *power division* among international actors.

   Furthermore, as regimes are expected to continuously operate as a critical instrument in managing climate change, sustaining cooperation with the method suggested by this chapter might be of importance. Some states or coalition groups trying to take the initiative might hamper the process of strengthening the position of post-developing countries. Thus, the ultimate success of this network depends on how astute the post-developing countries perform the task as a connector and translator. This chapter would leave it as a subject for future studies.

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The Effect of New Public Management Reforms on Climate Change Adaptive Capacity: A Comparison of Urban Planning and the Electricity Sector

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Contents

Abstract

From the mid-1980s and onwards, a number of public institutions in Western democracies were subject to New Public Management (NPM) reforms, applying management tools from the private sector, oriented towards outcomes and efficiency. The chapter identifies organizational factors that influence adaptive capacity to climate change and finds that the NPM reforms have changed the sectors, significantly reducing adaptive capacity to climate change. In urban planning project planning has been moved to private actors, undermining formal

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responsibility for adaptation. In addition, an increased focus on efficiency and short-term market orientation has reduced adaptive capacity. For the electricity sector, the revolutionary change with the reform in 1991 led to an abrupt undermining of adaptive capacity. The radical change in incentive structures, from encouraging security of supply to an extreme focus on economic efficiency, downplayed robustness and adaptation. The change in formal structure is followed by a corresponding professional demographic change which further undermines adaptive capacity. Whereas both sectors were previously dominated by engineers focusing on robustness of constructions and maintenance, many economists focusing on cost reduction and economic efficiency were employed as a result of NPM reforms.

The chapter shows that adaptive capacity to climate change is influenced by a wide set of organizational factors beyond the traditional discussions, which have important practical implications for public administration.

Keywords

Organizations • Adaptive capacity • Formal structure • Culture • Electricity sector • Urban planning • NPM • Institutional logics • NPM

Introduction

From the late 1980s and onwards, a number of public institutions in Western democracies were subject to the so-called New Public Management (NPM) reforms, which applied management tools from the private sector, oriented towards outcomes and efficiency. These reforms have arguably transformed public organizations in the Western world from unitary and hierarchically managed organizations to more loosely organized clusters of interrelated organizations, with specified tasks. At the same time, climate change poses new challenges within key sectors (O'Brien and Leichenko 2008). With expected higher general levels of precipitation, floods, landslides, and possibly extreme winds, the necessity of implementing climate change adaptation measures is clear. However, the capacity to do so is not necessarily equally present across sectors. This chapter asks how NPM reforms have influenced the capacity to adapt to climate change in two policy areas that stand out as especially affected by changing climate patterns: urban planning and the electricity sector. Comparisons of the organization of public administration and adaptive capacity have been made diachronically within the same sector(s) both between and within countries and between sectors in different countries (see, e.g., Eakin et al. 2011; Huntjens et al. 2012; Eriksen and Selboe 2011; Inderberg 2011). Comparisons between sectors within the same national context are pertinent, however, since it allows us to study how sector-specific effects of organizational reforms affect adaptation capacity differently. This chapter compares the influence of NPM reforms in two different areas within the same national context, using urban planning and the electricity sector in Norway as cases.

The electricity sector and the urban planning sector both represent systems that society is dependent upon, and they both administer critical infrastructure which is geographically widespread, exposed to weather and change in climate. In other respects, the sectors are quite different. While the electricity sector takes responsibility for a limited set of goals, providing a reliable electricity supply to feed end users in an efficient manner, urban planning takes care of a multitude of considerations.

Adaptive capacity has been argued to be resource dependent (Smit and Pilifosova 2003). Norway is known to be rich in natural, financial, and knowledge resources and is therefore generally expected to yield a high adaptive capacity, and in order to shed light on a wider set of barriers to adaptation, Norway is therefore a good choice of case (O'Brien et al. 2006).

In Norway NPM reforms initially fell on barren grounds (Christensen et al. 2007). Eventually, however, NPM reforms were implemented in most sectors, although at different speeds and with sector-specific adjustments. While NPM as a reform wave has been claimed to be in decline, it still yields a prevailing legacy in the public sector (Christensen et al. 2007). Both the urban planning and the electricity sector have in Norway undergone reorganization according to NPM principles, although the specific design of the reforms and the way in which the reforms came about differ greatly. While the electricity sector saw a politically decided total and sudden restructuring, the planning sector gradually developed into a more market-oriented organization form. However, slow changes by no means mean less radical changes over time.

NPM reforms have been shown to alter not only the formal organizational structure but also organizations' cultures and ways of thinking (Inderberg 2011). These dimensions can again influence each other. To come to grips with the effect of NPM reforms on adaptive capacity, both an instrumental and a cultural perspective are applied.

The chapter starts with a presentation of two perspectives on NPM and adaptive capacity. Next, the empirical basis of the study is described and the research elaborated. Third, the two sectors and the changes introduced by NPM reforms are briefly described. In section four, the influence of NPM on adaptive capacity in the two sectors is analyzed and compared, both between the two sectors and also implicitly diachronically between pre- and post-NPM reforms in the two sectors.

Comparisons between the two sectors are set up along the dimensions of formal structure and organizational culture. Data has been gathered through formal documents, research articles, and in particular for the institutional-cultural perspective through extensive interviewing. Representatives of various types of actors from the energy sector and the planning sector have been through semi-structured interviews. For the electricity sector the interviews have been conducted with representatives from public officials in the Norwegian Water Resources and Energy Directorate (NVE), with company representatives and interest organizations, along with public officials. In the urban planning sector, interviews have been conducted in ten municipalities with representatives involved in urban planning, including municipal planners, politicians, architects, and private developers. Altogether, 57 interviews with 97 different persons in urban development were conducted in the period between September 2008 and December 2010. In both sectors, informants have been asked specific questions about formal structures, laws, and regulations and also about change in culture, appropriate courses of action, and modes of behavior over time.

Two Perspectives on NMP and Adaptive Capacity

The chapter assumes that the adaptive capacity of an entity, understood as its "ability or potential to respond successfully to climate variability and change" (IPCC 2007, p. 727), will be affected by the way the sector is organized as well as by specific sector characteristics. With the change caused by the NPM reforms in mind, it is natural to ask how this will influence the capacity to adapt to climate change (Eakin et al. 2011).

On the one hand, NPM reforms have been shown to empower and make leeway for managers to act, to clarify responsibilities, and to create important flexibility for the organizational units. On the other hand, NPM has been criticized for being too one-dimensional in emphasizing efficiency (Christensen et al. 2007). Taking its objectives not from democratic ideals but from market economics (Stoker 1998), it can undermine important considerations within public administration. Various traits associated with NPM, such as managerialism, lack of coordination between organizational units, and narrowing down scope for inherently complex issues, can lead to a reduced policy capacity to handle complex challenges (Painter 2001). Moreover, NPM can be said to lead to change, for example, in public sector legitimacy (Gregory 2001), and the use of individual auditing procedures for goal achievements changes civil servants' feeling of responsibility and narrows the scope of possible action (Shore 2008).

NPM reforms' influence on adaptive capacity can be studied from an instrumental and an institutional perspective. The instrumental perspective assumes that formal structures influence and channel attitudes and actions (Christensen et al. 2007, p. 144). Formal structure describes the explicitly regulated relations between actors at different levels and influence who can do what and how. Formal structures are seen as tools or instruments for organizational goal achievement, and adaptive capacity will in this perspective be contingent on organizational coordination and on the clarity of the distribution of responsibility embedded within the formal structure in the form of directives, incentives, and sanctions (Christensen et al. 2007). The formal structure can be changed in short time to fit the various goals set, and since actions are assumed to be influenced by the formal structure, such changes in formal structure will lead to a change in organizational outcome. The capacity to adapt, therefore, is in this perspective a function of the extent to which adaptive capacity is a prioritized goal and the effectiveness with which the organizational structure is oriented to goal achievement.

A high adaptive capacity will mean a clear distribution of responsibility; efficient coordination of the actions of involved actors in combination with clear expectations and incentives (resources and/or coercion), in the form of directives and legally binding regulations on issues of long-term perspective; robust construction; and location of physical structures. Where relevant, a formal structure that supports mapping of vulnerabilities as well as vulnerability-reducing investments and maintenance will also increase adaptive capacity.

In urban planning, the formal structure in particular regulates the relationship between national, county, and municipal government and private developers. In the electricity sector, the formal structure includes the whole sector from grid companies or entrepreneurs, via the administrative level and the regulators, to the ministry level.

The *institutional-cultural* perspective claims that actors within an organizational field can be seen as constrained by *institutional factors*: "more-or-less taken-for-granted repetitive social behaviour that is underpinned by normative systems and cognitive understandings that [...] enable self-reproducing social order" (Greenwood et al. 2008, pp. 4–5). Institutional factors are understood as relatively stable norms, values, and routines both constraining and empowering action.

Individuals and organizations fulfil or enact identities by following informal rules and procedures that they imagine as appropriate to the situation they are facing (March 1994). Actors thus act out what they believe is expected of them, and action is decided by norms and values. Action, then, is what is deemed appropriate by an actor in a process whereby situation and roles are matched (Christensen and Røvik 1999; March and Olsen 1989). Also, different appropriate behaviors can manifest in *institutional logics* within the same institutional setting, where contradictory practices and beliefs exist (Thornton and Ocasio 2008). Institutional logics can be coupled to professional background (Reay and Hinings 2009) and may compete, coexist, or get defined out, sometimes through change in organizational demography or location (Lounsbury 2007; Reay and Hinings 2009). Institutional logics can often be identified by looking at how organizational actors argue for or against, for example, specific solutions to problems, how specific situations are defined, and through perceptions about what is expected from them in particular situations.

Change in and the relative balance between institutional logics is important for adaptive capacity. Barriers to adaptation will exist where the institutionalized values do not provide a legitimate basis for the implementation of adaptive measures. Therefore, if the NPM has led to a change in institutional logics, this is likely to also influence adaptive capacity.

By this perspective a high adaptive capacity in urban planning and in the electricity sector would be when prevailing institutional logics legitimize climate vulnerability awareness and vulnerability reduction. This can, for example, be the use of climate change scenarios as a basis for decisions, emphasis on robustness, security, and maintenance of physical structures.

The Introduction of NPM into the Spatial Planning and Electricity Sectors

The Urban Planning Sector

Norway has introduced NPM reforms and market forms in urban planning to a greater extent than its neighboring countries (Hanssen and Saglie 2010). According to most of the interviews and as the Norwegian urban planning system is largely decentralized, the practical implications of the reforms have taken place at the local level. Planning authority pursuant to the Planning and Building Act (PBA) is delegated to the municipalities, with the local council as the primary decision maker. Since the mid-1980s, the authority of the national government has been restricted to issuing national guidelines for local planning and to giving final decisions on conflicting planning issues between the municipality and regional authorities (Kleven 2011). The most important NPM-inspired reform in the planning sector took place in 1985, when the PBA opened up for planning initiatives from private actors, thereby terminating the municipal plan monopoly for zoning plans. The formal structure was hence altered in 1985, and a cultural change followed suit: Gradually a new division of labor has emerged in which private developers are plan owners and plan formulators until the plan proposal is submitted, whereas the municipality has gradually taken the role of a more passive, responding approval authority (Høegh et al. 2004). Today, nearly 90 % of zoning plans are formulated by private actors (Falleth et al. 2010). These zoning plans are core documents for the regulation rights and core instruments in the control of urban development. In general, urban planning now tends to center on projects in the form of single zoning plans rather than proactive and comprehensive plans for the urban areas. The operation mode of spatial planning is consequently altered. Detailed formal planning (zoning plans) for urban development is no longer the prerogative of the municipalities. The plans still have to be approved by the local councils, but the plan initiative and plan formulation have in practice been delegated to private actors, and investors and private developers have gained an increasingly prominent position in urban planning and development (Mäntysalo et al. 2011; Nordahl 2006).

This development reflects a politically driven neoliberal trend with great impact on urban planning practice internationally, and the underlying idea corresponds with that of NPM, assuming increased efficiency through management by objectives (Hanssen and Saglie 2010). The ambitions of the municipalities are limited to manage the spatial development through their master plan according to the Planning and Building Act, and their role has increasingly become reactive instead of proactive. The situation is often characterized by negotiations between market actors and public authorities (Falleth et al. 2010; Klausen et al. Forthcoming 2015)). Market actors provide funding for much wanted development, which in turn gives these actors a strong bargain position vis-à-vis public authorities in defining "what to build where" (Falleth et al. 2010).

The workforce in urban planning has remained relatively stable in absolute numbers, although the staffs employed in the private sector have increased relative to the public sector. Urban planners, architects, and engineers dominate both in municipal planning departments and with private developers. Consultants, partly with background in economics, however, are gradually gaining a more prominent position, and they often function as intermediary between the public and the private part of the planning sector (Moen et al. 2004). At the same time, one can, according to the informants in the ten case municipalities, observe a gradual introduction of a new institutional logic related to some of the NPM tools, such as management by objectives. Whereas each project previously had a general responsibility for common public values such as the value of sustainable urban development, the projects are now more narrowly addressing the specific demands articulated in municipal directives and regulations or in the national Planning and Building Act. Goals that are not explicitly mentioned in core documents tend to be ignored.

The Energy Sector

Until 1991 the price of electricity in Norway was regulated through long-term contracts (Midttun and Summerton 1998). The sector was hierarchically regulated through direct public ownership and politically set prices, and largely vertically integrated, meaning that generation and transportation of electricity was usually performed by the same companies. In fact, most of the central grid was owned by state-owned Statkraft while still generating around one third of the nation's electricity (Bye and Hope 2006).

The companies often sold power at self-cost, because of considerations other than economic ones or simply because of lack of economic expertise. Combined with the fact that trade and consumption of electricity were largely domestically confined because of weak connections abroad, this contributed to a steady rise in consumption. Less attention was paid to the cost of projects, something that led to varying outcomes. All investments in production and capacity in this period were subject to cost reimbursement, either through direct market prices, cross-subsidization, or direct subsidies (Bye and Hope 2006).

In the period up to the point of the reform in 1991, emphasis was put on security of supply, as well as general industrial development in Norway. The engineer's values and logic of thinking largely represented the appropriate code of conduct. Other values current at the time were the industrial modernization of Norway, in which cheap electricity played an important part (Olsen 2000, p. 123). The interviewees that have experienced the time before 1991 confirm that the engineers were the dominant group within the sector, and they traditionally emphasized the structure of the grid – secure supply of energy – often over-dimensioning the structures to guard against exposure to climate loads. By the 1980s, however, most of Norway's major dam projects had been completed, and the leakage of expertise began. In addition, there was in the sector a rising awareness of the lack of efficiency and also a changing legitimacy basis due to increased awareness in the general population about the impacts made by hydropower projects on nature. The general view in the late 1980s was that something would have to be done to make the sector more cost-efficient (Thue 1996).

The Energy Act of 1990 was a radical reform resonating with many of the NPM characteristics (Olsen 2000, p. 123). Power suppliers were now to compete for customers through electricity prices set by the market. The act represented a new formal structure in which the power sector was to work. It disintegrated the earlier vertically integrated companies through unbundling production from transmission of electricity into a competitive market and monopolistic functions, respectively, the latter to be subject to government incentive regulation. Efficiency was the main goal of the reform; other public considerations downplayed. Among these was robustness in severe weather conditions, even though awareness to climate change rose on the agenda internationally. Seen in a longer perspective, division and specialization of the NVE in 1986 and devolution of responsibility were clearly inspired by NPM tendencies (Christensen and Lægreid 2001). The responsibility for security of supply was clear as seen by the Energy Law; the individual grid company was to be responsible for any blackout. However, would the regulatory framework provide room for investments for securing supply?

The changes went even further, making it justifiable to see the reform as a clear example of a New Public Management (NPM) reform, inspired by private corporative management (Olsen 2000, p. 180ff). The NVE gradually developed a model for incentive regulation of the grid companies, which was implemented in the later part of the period (Langset et al. 2001). With the model revenue caps could be estimated to use for economic incentive-based regulation of the grid companies. The more efficient the company, the more revenues they were to be allowed.

Investments in grid structures came to a halt, reflecting market-based risks and falling prices due to the massive surplus capacity that had been revealed. But investments made earlier provided some slack for maintenance without increasing vulnerability.

Less formal changes were also evident, although not always highly visible. The most prominent change is perhaps that the economic paradigm changed from a macro-oriented planned economy model to a more micro-based self-regulatory regime (Thue 1996). Along with this reorientation came the entry of the electricity economists. Until just before the reform, the economists as a group did not have any particular foothold within the sector. The market reform implied a change of professional boundaries. The sector was redefined from a primarily technical to a primarily economic issue, skewing the weight of professions towards economic expertise (Midttun 1996). This led to a change of appropriate values which undermined adaptive capacity, from the engineering logic to social economic values of efficiency.

The Effects of NPM Reforms on Adaptive Capacity

As shown above, in both urban planning and in the electricity sector, NPM reforms have carried with them new organizational structures and new institutional logics. Both sectors have become more decentralized and fragmented, and the responsibility for specific tasks has in some cases become unclear. Moreover, both sectors have experienced an increased focus on profit and an increased need to adapt the sectors to the market. In the following sections, how these changes affect the sectors' capacity to adapt to climate change is discussed.

Influence from Formal Organizational Structure

The distribution of responsibility for urban planning and development has been gradually altered along with the introduction of NPM reforms, starting in the mid-1980s. Whereas the municipality used to have the superior responsibility for the whole planning process, the responsibility is now decomposed into specified elements for which different actors, different sectors, and different governmental levels are responsible. The distribution of responsibility has become increasingly complex, and new issues, such as climate change adaptation, can easily be left untended. Document studies and interview data from the ten case municipalities suggest that this ambiguity and complexity in responsibility distribution has indeed been unfortunate for the sector's capacity of climate change adaptation. In this new and decentralized structure, it is increasingly difficult to formally include new considerations in the formal guidelines. Being a relatively new policy issue, the responsibility for climate change adaptation in urban planning has not been given to any actor or sector in particular, neither at the local nor at the national level. Nor has anyone taken the responsibility on a voluntary basis. When asked who is responsible, the developers point to the municipality, whereas the municipality points to the national government, which points back at the municipalities. As long as the municipalities do not receive legally binding directives from the national or regional level, they do not address the issue of climate change adaptation in any systematic way. When unmentioned in the legal framework, the issue is only accidentally addressed by actors who are interested on a private basis. To compensate for the reduced opportunity for direct intervention into planning, the Planning and Building Act contains detailed regulations which private developers must comply with. According to informants, the detailed law specifications at times result in what is perceived as a "regulation overload," exhausting both municipalities and developers and leaving little energy and few resources to consider nonmandatory issues, such as climate change adaptation. Based on the above, it is therefore reasonable to conclude that the gradual changes in the formal structure of spatial planning area have contributed to a reduction in adaptive capacity to climate change. The previous structure, with a clearer responsibility distribution, encouraged adaptations to a higher degree.

The electricity sector has also experienced changes in formal structure, although more abruptly and in a different manner. While the Energy Act divided the grid from the production segments in the organizational field, the grid part, being a natural monopoly, was put under governmental incentive regulation. The responsibility distribution may seem clear on the surface, since the grid company is formally responsible for any failures no matter the cause of them (OED 1990). However, implicit in the structure is also an inherent issue of regulation, in relation with resource availability. Since the grid companies are formally responsible for any failures, it is also their responsibility to invest in maintenance and mapping potential problems. However, this is undermined if the companies through the regulatory scheme are driven one-sidedly on economic efficiency, leading to a potential responsibility gap (Palm 2008). Who is responsible if the companies do not have the framework conditions to make the necessary investments in a robust grid. This unclear responsibility structure did not exist prior to the 1990 Energy Act and clearly brings out ambiguities about responsibility within the formal structure which reduces adaptive capacity.

The multi-sector nature of planning further clouds the question of responsibility. Spatial planning includes economic actors (developers), the municipal planning section, as well as other technical sections, and the plans are sent on hearing to several institutions on different administrative levels and to civil society organizations. The planning process is designed to take care of the varying institutional goals of all these different sectors and actors, and this makes the decision situation complex. The interview data indicate that the large number of different actors that are responsible undermines adaptive capacity, through two different mechanisms. First, as mentioned above, the responsibility not being formally placed combined with a large number of potentially responsible actors leads to collective inaction. Everyone waits for each other to act. Second, when a decision shall be made, multiple goals must be weighted. In this weighting process, climate change adaptation tends to losing against other competing goals such as private developers more short-term and more concrete interests. The field of electricity grid contains fewer different actor types to regulate and is more transparent. The structure of the field is much simpler than that of the urban planning and largely contains three types of actors: privately and publicly owned grid companies; the Transmission Grid Operator (TSO), which owns and operates the main transmission grid; interest associations; the regulator of the Norwegian Directorate for Watercourses and Energy (NVE); and the Ministry of Petroleum and Energy (OED).

When responsibility is spread on many actors, the mechanism for coordinating these actors becomes important. In the land-use planning sector, the main coordination mechanism is the Planning and Building Act, through which the roles and responsibilities of the actors are coordinated. The planning process has several stages, starting with the municipal governments developing overarching master plans for larger areas. Within the frame of the master plans, private developers initiate specific zoning plans that are to be realized. These are sent on hearing to all relevant stakeholders and eventually recommended by the planning authorities and sanctioned by the politicians. Throughout this process there is a lot of both formal and informal contact between the involved actors, and a lot of coordination efforts happen through dialogue and negotiations between the municipality, the private developer, and different regional agencies. These negotiations provide ample space for climate change adaptation to be launched as a subject, but as long as adaptation is not required in the Planning and Building Act, this requires a certain amount of awareness and motivation either with the developers or with the municipal staff.

The planning process mirrors the fundamental principles of NPM organization: The municipality sets the overarching goals in their master plan, outsources the more detailed planning to private actors, and finally controls that these private plans comply with the specifications and goals in the overarching plan. A consequence of this way of organizing the planning process is that measures necessary for climate change adaptation must be articulated as regulations in the overarching municipal master plan, prior to the development of detailed plans. In the more hierarchical pre-NPM system, where authorities were responsible for plans at a more detailed level, issues such as adaptation could be planned and implemented as integrated elements of comprehensive projects. Regarding the possibilities for good climate change adaptation solutions, the fact that private developers are responsible for developing the plans is, according to the informants, believed to reduce the action space for the planning authorities. They can regulate in advance and respond afterward but have less chance to be actively involved in the actual development of specific areas. This illustrates a general problem with NPM organization and management by objectives. The possibility of focusing on new policy areas, such as climate change adaptation, depends on these policy areas being articulated in the formal overarching goals at an early stage. Contrary to the theoretical assumptions, the NPM-oriented system as applied in urban planning seems to be surprisingly inflexible and unable to include new goals and priorities along the way. The power that the planning authorities had before the introduction of NPM, to rapidly adjust to new policy areas and to intervene in ongoing projects, is lost when they do not longer possess the skills or mandate to do the detailed planning. Moreover, their capability for controlling the detailed plans is weakened as they no longer carry out the task of detailed planning and only have desk experience. This competency now rests with the developers and their hired consultants. It must be noted, however, that a hierarchical system can also be slow and inflexible, as decisions must be taken on top and passed down to the implementing level. In the current system, although the different actors in urban planning do not systematically address the issue of climate change adaptation, they are free to do so should they wish, as long as they also fulfil the overarching goals.

Influence from Organizational Culture

Contrary to the instrumental perspective, the institutional-cultural perspective claims that institutional logics and organizational culture strongly shape the range of possible actions for organizational field actors. This happens through mechanisms of *legitimacy* or *appropriate actions*, as accepted within the organizational field. Evident in the electricity sector is a change in institutional logic. This usually happens over time (March and Olsen 1989), although interviews with representatives from the companies and the regulator point to the fact that the strong and rapid restructuring of the sector, along with the delegitimization of the economic inefficiencies leading up to the reform in 1991, led to an incursion of economists in the sector.

The institutional logic in the sector up to the reform legitimized decisions that increased system reliability, security of supply, and system robustness – all while disregarding the economic cost related to these decisions. This engineer's logic encouraged many grid companies, including TSO Statnett, to construct an over-robust grid, something that led to a high adaptive capacity while downplaying the economic costs. Leading up to the Energy Act of 1990, the economist entered the field as an increasingly dominant professional group. Even though there does not exist precise data about the changes in professional demography around this period, the interviews broadly confirm the changes in demography and more importantly the changes that followed in institutional culture.

The process itself was a response to the delegitimization of the engineer's logic in the Norwegian electricity sector. When the alternative norm set presented itself and was emphasized also in the formal structure, it was quickly accepted as legitimate. The new economist institutional logic was as much a product of the reform as the reform was a product of the logic, since both found their legitimacy in the economic efficiency paradigm which easily took the place of the delegitimized engineer's logic.

This new economist's logic has increased legitimacy over time, at least up until the mid-2000s. It is common for actors with noneconomic background to receive courses in economy, as several of the interviewees exemplify. Decisions have to be legitimized by economic arguments whereas earlier it was a system performance focus. This change is more than mere rhetoric; it represents a transformation of cultural basis in the sector that largely influences the real room of decisional maneuverability – and therefore adaptive capacity to climate change.

The economist's logic legitimates decisions which are economically "efficient," reducing the appropriateness in the sector of decisions that are not grounded in economic arguments. In fact the main grid operator Statnett, according to company interviewees, officially operates under instruction of "social economic feasibility." In practice this means that no grid should be constructed unless grounded in the principle of marginal pricing. Since adaptations are often difficult to calculate on grid level, grid adaptations are often left out, something that has been shown to lead to less adaptation in Norwegian grid companies when compared to countries such as Sweden (Inderberg and Arntzen Løchen 2012). Robustness is regarded as a less legitimate goal than economic efficiency in the new institutional logic, and maintenance and security of supply are sometimes regarded as necessary evils that influence efficiency rather than legitimate goals in themselves.

The consequences of the cultural transformation in the electricity grid sector for adaptive capacity can be summed up to that the earlier logic of the engineer encouraged robustness and maintenance to meet challenges to system reliability – possibly disregarding important efficiency considerations. However, the economic paradigm from the early 1990s has overcompensated, with one of the consequences being an undermining of adaptive capacity to climate change within the electricity sector.

The restructuring of the urban planning sector has also seemingly entailed a change in its institutional logic, which can be inferred from how the actors perceive the goals and norms of the sector. With transfer of planning power from the public to the private part of the sector, many of the interviewees in the case municipalities report of a shift in focus from comprehensive urban development encompassing various societal goals to economic gain and market considerations. This corresponds with the goals and values in the two sectors, respectively, and should therefore come as no surprise. The focus on economic gain and market mechanisms as guiding principle in urban planning has its normative basis in the belief that the prize mechanism will merge demand and offer so that the needs of the population are met. Currently, however, the population does not display a need of climate-adapted urban development, and relying on market mechanisms in this regard therefore leads to little or no adaptation. Interestingly, also representatives from the municipal planning departments use this kind of market argumentation, largely accepting the developers' market considerations and objections to adapting to climate change, as valid. The norm that the market knows best has trickled into the public administration as well, and this fact allocates much power to the private developers.

While doing what is good for society is the municipalities' *raison d'être*, for the developers, social responsibility is a more voluntary consideration to make. Whether the private developers as they gain power and their role becomes more important will take responsibility for nonprofitable common interests in urban development such as the need for climate change adaptation remains a question. There are examples in the data indicating that especially some of the big developers do, although there is no systematic trend. About half of the developers interviewed had on their own initiative made some considerations regarding climate change adaptation, and three of them had also taken some adaptation measures, such as increasing building height near the sea shore. But still, such a transfer of power to the market actors does appear to reduce adaptive capacity.

The guiding norms of the planning departments can to some extent be read off the planning department's self-image or identity, something that the interview data indicates varies across the ten case cities. Whereas planning departments in some cities define their role mainly as that of controlling whether plans comply with the formal regulations, other cities have ambitions of being in front in climate change adaptation, both in supplying the terms for urban development and in ensuring that private zoning plans are adapted to future climate change by integrating requirements in their master plan. Causes for differences in municipal self-image have not been looked into, but the presence of dedicated individuals in central positions is a factor that has been found to contribute (Klausen et al. Forthcoming 2015). This means that there are different reasons for adaptation to rise on the agenda, but from an organizational perspective, there is a need to manage adaptation within the organizational structure, in order to not be dependent on "random" dedicated individuals.

Furthermore, the responsibility taken by private developers is likely to change over time. Contrary to the energy sector, NPM reforms have been introduced in the planning sector at a slow rate. The actors in urban planning have therefore, cognitively, to some extent remained inside the hierarchical system. They do not fully comprehend their new role, with an increased responsibility for urban planning as such, and still wait for authoritative signals before they act.

In the institutional-cultural perspective, a sector holds high adaptive capacity if climate change knowledge such as downscaled scenarios was perceived as a valid basis for decision making, along with valuing robustness and adaptations as a basis for decisions. This is to some extent the case in the case municipalities, but when lacking specific regulations and laws, the municipal employees largely underline the need of complying with the norms of society. If the general attitude is that climate change adaptation is not worth spending money on, and if this attitude also prevails with the private developers, municipal planning departments find it hard to use climate change scenarios as arguments for demanding that measures be taken. In such cases where their demands do not comply with the general norms, they feel they need more proof of the coming changes. This is perceived as a lack of relevant information but is often indeed more a lack of information that is perceived as sufficiently valid by the involved actors in urban development and planning.

When planning initiative was delegated to private developers, the culture in the planning sector also seems to have been more law oriented, following standard deregulation theory (Vogel 1996). As the municipalities have been relegated to a role as regulators, the law remains their most important steering tool. When the municipalities were more actively involved in planning, there was, according to informants, more room for discretion. The hands-off steering hence leads to increased focus on rules and regulations, and has further increased the threshold for involved actors to take up nonregulated issues such as climate change adaptation, and this has contributed to a reduction in adaptive capacity.

Although the institutional logic may have changed towards an increased focus on efficiency and market profit, with the introduction of NPM in the planning sector, some professional norms seem to have remained important throughout these changes, according to the informants. The relative strength between municipal bureaucrats and private developers have changed with the NPM reforms, but engineers and architects still play a pivotal role in providing terms for building projects, and they are still occupied by things such as safety and robustness. The professional norms of engineers and architects are in the municipalities observed to be the primary drivers for climate change adaptation.

Conclusions

The chapter has analyzed the climate change adaptive capacity in Norway's urban planning sector and electricity grid sector and the changes in such capacity over the implementation of New Public Management (NPM) reforms. The chapter shows that with the introduction of NPM in the energy sector, the focus changed from system reliability and societal security to economic efficiency. This change in focus happened surprisingly rapidly because professions advocating economic efficiency were extensively recruited and because of the introduction of piecemeal incentive structures and soon outweighed the professions advocating security and the need for robust solutions. In urban planning, a slower process occurred. The introduction of NPM reforms in this sector did change the structure in the area. Where the municipalities were previously behind the planning initiatives taken in the sector, today the entrepreneurs commonly provide the planning proposals. This has changed the dynamic and the central focus from sustainable urban development to the favor of economic considerations. This change has taken place more slowly than in the energy sector, as market-based stakeholder groups gradually have gained more definition power as well as implementation power in the planning process. In both sectors, however, these different changes have resulted in a decrease of adaptive capacity, indicating some equifinality.

Two perspectives have been applied to analyze the changes in adaptive capacity: an instrumental and an institutional perspective. From an instrumental perspective, the NPM reforms have decreased adaptive capacity in both sectors, although the picture is somewhat ambiguous. Particularly two elements of the NPM reforms have affected the structural adaptive capacity of the institutions: management by objectives and delegation of responsibility to independent units not subsumed under the hierarchical structure. In the planning sector, management by objectives, in particular, implies that the objectives for urban planning are defined on the top level, with the politicians. In many of the studied municipalities, the need for adaptation was detected at lower levels in the municipality, for example, with the planning department, but was not addressed until objectives were redefined at the top level, which had not yet happened in the bulk of the case municipalities nor in most Norwegian municipalities (Harvold and Risan 2010). The NPM logic requires that all new policy issues must first be addressed at the top level (often in the form of law), and this makes the system slow in incorporating new goals such as climate change adaptation. When not articulated as a goal at the top level, responsibility for climate change adaptation is not delegated, and when not delegated, not addressed. It must be noted, however, that unlike in the more hierarchical system that prevailed 30 years ago, actors at all levels and in all sectors are free to address the issue of adaptation if they like, and although this rarely happens, there are examples of planning departments and private developers taking action also on their own initiative.

Since adaptation often has wide, abstract, and few short-term benefits when compared to other goals, it risks being prioritized down. Being perceived as a mere expense, climate change adaptation is even more in need of being articulated and delegated and included as a separate goal, within a NPM system, in order to be addressed. Adaptation is therefore vulnerable to unclear responsibility structures. NPM has been criticized for dividing organization into silos (Painter 2001). With cross-sectoral issues such as climate change adaptation that do not easily fit into clear manageable categories, the capacity to manage adaptation and vulnerability reduction is reduced in both the systems analyzed here.

Being a sector mainly responsible for one task, the responsibility structure is clearer in the electricity sector than in the urban planning system. The multi-sector nature of urban planning and the sector's ensuing need to take various interests into account in all decision making further complicate the status of climate change adaptation as a policy issue. Adaptation must compete with the interests of many powerful stakeholder groups, and as long as it is not explicitly delegated to a given organizational entity, it risks being downplayed, and the material shows that in such situations, adaptation can turn into a question of dedicated individuals.

Cultural changes have taken place at a fast rate in the energy sector while in the planning sector the changes have been more gradual. This indicates that professions are strong drivers for changing norms than actor groups or sectors. In both sectors, at least partial prevalence of professional norms guaranteeing a certain level of climate change adaptation was observed, even if the formal organizational structures do not incentivize it (Inderberg 2011).

In sum a reduction in adaptive capacity for both the electricity grid sector and for urban spatial planning after the introduction of the NPM reforms is found. This reduction takes place both because of the changes in formal organizational structures and changes in organizational culture. With increasing challenges to public authorities that require holistic responses instead of piecemeal solutions, there is a need for public administration to emphasize coordination of policy and long-term considerations. Building adaptive capacity means not only access to information and financial resources, but is dependent on adaptation being appropriate considerations, that responsibility in the institutional structure is clear, and that incentive structures are aligned with adaptation as a valued goal.

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The Role of National Development Banks in Catalyzing International Climate Finance: Empirical Evidences from Latin America

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Contents

Abstract

Significant investments are needed to support the global transition to a low-carbon, climate-resilient future. Unlocking private capital at scale is

This chapter is a shorter and adapted version of Smallridge et al. (2013), which was prepared based on the results of a survey, and a series of interviews undertaken between April and July 2012 to 9 (nine) national development banks from the Latin American and the Caribbean region, and a series of workshops and dialogues organized by the IDB over the course of 2011–2012. Several professionals contributed their expertise for the development and review of the research study.

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essential to fill the current financing gap and achieve *transformational* impacts, but there are several barriers to overcome for this to happen.

This study sought to analyze the role that national development banks (NDBs) could play to bridge the financing gap by scaling up private investment. Their knowledge and long-standing relationship with the local private sector places them in a privileged position to understand local barriers to investment as well as risks and opportunities.

Drawing empirical evidence from NDBs' experiences within the Latin American and the Caribbean (LAC) region, the study finds that while many NDBs are already piloting an array of financial and nonfinancial instruments to promote and leverage private low-carbon investments, these institutions are at diverse stages of "readiness" to fully promote climate-related programs. Several NDBs still need to build and/or strengthen capacity and acquire experience in the structuring, risk assessment, and monitoring of climate-relevant projects in order to take a more central role in the international climate finance landscape.

Keywords

National Development Banks • Low carbon • Climate finance • Private finance • Latin America and the Caribbean

Introduction

Climate finance has become a key topic in international climate negotiations over the past years, as it is a critical element to address the global climate change challenge. Large-scale investments are required to support countries' transition toward a low-carbon and climate-resilient development path (Buchner et al. 2012 based on IEA 2012; World Bank 2010). This has resulted in a developed countries' commitment to mobilize US$100 billion per year by 2020, to collectively support developing countries' mitigation and adaptation needs to respond more effectively to the climate change challenge (UNFCCC 1/CP.16).

Annual global support to low-emission, climate-resilient development activities is estimated in the range of US$ 343–385 billion for 2011, about 47 % of which invested in projects in developing countries (Buchner et al. 2012). While this is a start, this level of investment is far from what is required. The IEA (2012), for instance, suggests that over the 2012–2050 approximately US$ 1 trillion each year will be needed to finance incremental investment in the energy sector alone to promote a low-emission growth. Financial resources have therefore to be scaled up significantly to foster a sustainable development pathway and to address mitigation activities and adaptation needs of a world on a path to 4 °C temperature increase (World Bank 2012; UNFCCC 2008).

Unlocking private sector capital will be essential to ensure large, *transformational*, and long-term impacts across all economies given that public resources are far too scarce to finance the transition alone, particularly in times of fiscal austerity (e.g., OECD 2012). Increased private sector engagement in these activities will also help to reduce the reliance on international and national public finance in the long run and to seeking out and implementing least cost options for climate mitigation and adaptation.

However, efforts to date have not yet been able to mobilize private financing for climate change projects at the scale and speed required (e.g., AGF 2010; The World Bank 2010; Brown and Jacob 2011; UNEP-FI 2009).

In practice, it is challenging to align private sector incentives with public goals. Significant questions remain about how to best mobilize private climate investments and how to design risk-return arrangements that are attractive to private, but also public actors' investments. International climate finance can play a catalytic role in this regard, and national development banks (NDBs) can help to overcome some of the difficulties.

While, until recently, little attention has been paid to NDBs' role in raising and delivering climate finance, the international climate finance community is increasingly aware of NDBs' potential to promote and catalyze private climate finance in developing and emerging countries. This growing awareness is also confirmed by, for instance, the establishment of the International Development Finance Club (IDFC), a network of renowned national and subregional development banks with total assets of more than USD 2.1 trillion (see IDFC.org).

NDBs can play a potentially crucial role in facilitating climate investments and delivering climate finance directly to investors or by leveraging private capital. Their focus is unique, particularly compared to other national public institutions and international financial institutions intermediating climate finance. NDBs are mandated by their respective governments to support the fulfillment of national low-carbon resilient development goals and plans and have the backing of their governments to do so.

Furthermore, NDBs' knowledge and long-standing relationship with their local markets and institutions places them in a privileged position to understand local barriers to investment and opportunities, thereby favoring the financing of private sector activities. NDBs seem to understand better than many other players the conditions necessary on the ground for long-term investment and can better assemble the financing packages tailored to the needs of domestic investors (authors' elaboration based on ALIDE et al. 2012).

NDBs are already playing a significant role in the climate change finance landscape. In 2011 alone, a selected number of NDBs provided around US$ 42.7 billion in financing to programs addressing climate change, around 55.6 % of the total climate finance distributed by public intermediaries (Buchner et al. 2012).

The question is: How could they do more and fully harness their potential? More evidence is needed to understand the conditions and the institutional capacities required for NDBs to become more proactive and effective intermediaries in climate finance.

This research aims to build knowledge and evidence about the key role of NDBs in the climate finance landscape, and the conditions that would enable them to channeling and leveraging climate finance in the most effective way. Specifically, this research analyzes the leverage potential of NDBs, by looking at their unique characteristics and role in scaling up private sector financing for climate change mitigation projects and programs through the leveraging of international and national climate finance in their respective markets. The study does not specifically assess the role NDBs could play to scale up financing of climate change adaptation due to the complexities associated to what is and what counts as adaptation finance and tracking issues (see, e.g., Terpstra 2013 and Jones et al. 2012).

To this end, the study draws empirical evidence from NDBs in the Latin American and the Caribbean region (LAC) – where NDBs have a long tradition and experience in financing private sector investments – by assessing and presenting:

- The key features of NDBs (section "Key Features of NDBs to Scale Up Climate Finance")
- The type of financial and nonfinancial instruments at their disposal to promote private investment in low-carbon, climate-resilient activities and scale up climate finance efforts (section "NDBs' Financial Instruments to Promote Private Finance and Scale Up Investments")
- NDBs' current involvement in the climate finance landscape – i.e., volume of financial resources committed, dedicated financing programs, and participation in international initiatives – and their level of "readiness," i.e., of institutional and technical development (section "Overview of NDBs in the Latin American and the Caribbean Region")
- NDBs' leverage potential (section "How NDBs Can Leverage Private Finance")

A better understanding of these aspects could help NDBs to develop a proactive and efficient strategy for playing a greater role in the international climate finance architecture, in terms of both accessing and leveraging finance from a broader range of sources, and influencing the operational design of future delivery climate mechanisms and channels such as the Green Climate Fund (GCF). The study concludes offering recommendations on how to fully enable these players to scale up investments to the scale needed.

The study adopts a multi-method approach comprising of: (i) a financial survey, (ii) interviews to NDBs, (iii) desk-based analysis, and (iv) a case study approach. It also incorporates insights from a series of workshops and dialogues organized by the Inter-American Development Bank (IADB) in 2011–2012 (see, e.g., ALIDE et al. 2012).

The financial survey was undertaken to elicit the main features of NDBs operating in the LAC region. It contained a series of questions aimed to understand NDBs financial and business activities, the instruments used, and their level of involvement in climate financing and tracking of private finance mobilized. The survey was conducted between April and July 2012 to the NDBs' members of the Latin American Association of Financial Institutions for Development (ALIDE), and targeted nine (9) NDBs involved in climate financing to different extents, and at different stages of institutional development. This sample included the largest NDBs in the region, representing over one-third of the region's NDBs' assets and capital. Concerned NDBs are Agencia Financiera de Desarrollo (AFD) (Paraguay), Banco del Estado del Ecuador (BEDE) (Ecuador), Banco de Comercio Exterior de Colombia (BANCOLDEX) (Colombia), Banco de Desarrollo de El Salvador

(BANDESAL) (El Salvador), Banco Nacional de Desenvolvimento Econômico e Social (BNDES) (Brazil), Corporación Financiera de Desarrollo (COFIDE) (Peru), Fideicomisos Instituidos en Relación con la Agricultura (FIRA) (Mexico), Financiera de Desarrollo Territorial (FINDETER) (Colombia), and Financiera Rural (FINRURAL) (Mexico).

While there is not yet an internationally acknowledged definition of climate finance, the term refers to both public and private.

Following Buchner et al. (2011, 2012, 2013) and given the lack of an internationally acknowledged definition, in this study, climate finance refers to both public and private resources targeting low-carbon and climate-resilient development, with direct and indirect greenhouse gas mitigation or adaptation objectives/outcomes. To determine whether an activity qualifies as mitigation and/or adaptation, the study follows the criteria of the OECD-Development Assistance Committee Creditor Reporting System (see OECD 2011).

Key Features of NDBs to Scale Up Climate Finance

NDBs are well suited to play a critical role in climate finance by delivering financial resources directly to support climate-relevant projects and programs and/or by leveraging private capital toward this end. This is thanks to a number of characteristics (see Fig. 1 which, based on ALIDE et al. (2012), Smallridge et al. (2012) and UN (2006), presents NDBs' key features at a glance), which are also confirmed in concrete examples drawn from NDBs' experiences within the LAC region

I. *Development Mandate*: NDBs are mandated and supported by their respective governments to provide long-term financing to sectors promoting economic and sustainable development, particularly to projects, activities, or sectors of the economy that are underserved by private sources of finance (UN 2006) such as climate-relevant sectors (i.e., energy efficiency and renewable energy). By providing capital at terms and conditions generally more favorable than those prevailing on the market, they help to improve the risk-return profiles of climate mitigation projects, thereby enhancing their attractiveness to investors and encouraging low-carbon technologies to scale up.

> The Brazilian Development Bank (BNDES) places sustainable development at the core of its operations, which is proven by its significant support to the rollout of the country's renewable energy, energy efficiency, and deforestation programs (BNDES.gov.br, BNDES 2012). In 2011, BNDES' disbursements to renewable energy and energy efficiency reached about US\$ 7.2 billion (R\$ 12.3 billion), 31 % higher than in 2008, making it the largest provider of credit to the country's clean energy sector (Buchner et al. 2012, IRENA 2012).

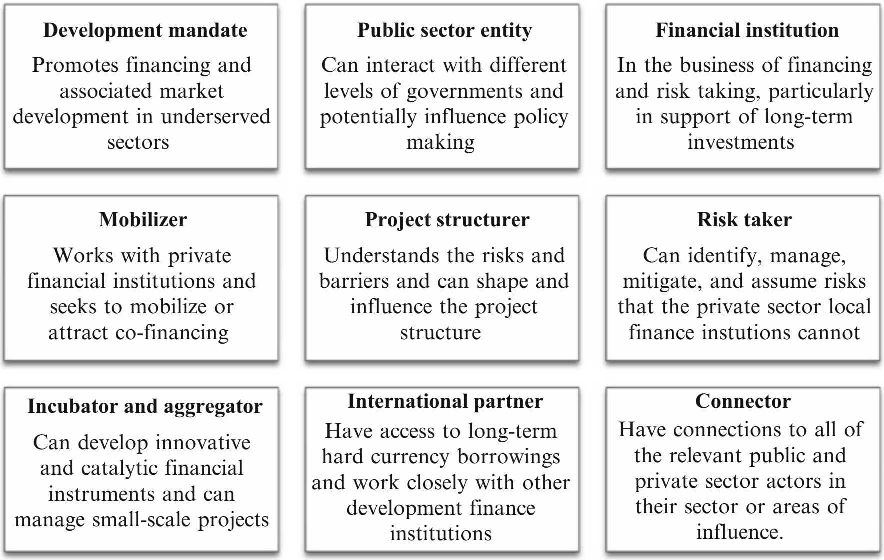

Fig. 1 The key features of National Development Banks (source: Authors' elaborations based on, e.g., Smallridge et al. (2012), ALIDE et al. (2012), UN (2006))

II. *Public Sector Entity*: NDBs have strong relationships with national government and hence can interact with different government agencies and administer nonreimbursable budgetary resources to support national or subnational priority programs, including climate-relevant projects promoted by private sector actors. Because of their involvement and interaction with the financial and nonfinancial private sectors, NDBs can also contribute to policymaking, sharing information about impacts and implementation of various policy options. This is particularly important to create the conditions necessary to scale up climate finance to mitigate climate change and adapt to its impacts.

III. *Financial Institution*: NDBs are in the business of financing and risk taking, particularly in support of long-term investments. Indeed, NDBs are first and foremost financial institutions, often under the same bank supervision rules as commercial banks. They can be mandated to support improvement of financial conditions in local financial markets by "crowding-in" private financial intermediaries into new and innovative areas of investment.

IV. *Mobilizer*: It is typically not in the nature of NDBs to compete. They are expected to complement and "crowd-in" private financial intermediaries by providing appropriate financial and nonfinancial instruments. This role is particularly relevant for leveraging private capital for climate financing. In the fulfillment of their mandate, however, NDBs may also have a reverse effect, "crowding-out" private sector investment or lending.

V. *Project Structurer*: NDBs can promote market development through the provision of additional resources, such as technical assistance, capacity building, and training to project developers, and small- and medium-sized enterprises, to create the demand for financing by helping to develop and structure projects and programs. They also can put together financing packages with terms and conditions in line with local project developers' needs, taking into account local market specificities. It should be noted, however, that many NDBs still have to develop the capabilities necessary to evaluate, analyze, and structure low-carbon projects (Buchner et al. 2012; ALIDE et al. 2012).

In 2006, BANDESAL, the Development Bank of El Salvador established "Empresa Renovable," a financing program aimed to promote micro-, small-, and medium-sized enterprise investments in industrial energy conversion, energy efficiency, and renewable energy (mainly solar PV and small hydro). To incentivize investments, it structured a program entailing:

- A technical assistance grant covering a portion of the costs of feasibility studies and consultancy services to overcome knowledge and capacity barriers
- A credit line at preferred terms and conditions to overcome the lack of long-term finance at competitive rates for investment in these sectors (Bandesal 2012)

VI. *Risk Taker*: NDBs have long-standing relationships with local private sector financial institutions and hence understand the risks and barriers that these institutions confront when financing underserved sectors. Moreover, NDBs – which generally benefit from governments' guarantees – can assume certain project risks that private sector entities cannot or will not take, and therefore can draw incremental private capital into projects.

This is particularly relevant for renewable energy investors whose central challenge is getting an attractive return for the risks taken.

FIRA, a Mexican second-tier development bank, has historically acted as a risk taker, offering guarantee products to tier 1 banks and other financial intermediaries to share the risk of lending, hence facilitating access to credit to local private investors.

To overcome private banks' reluctance in financing renewable energy projects, FIRA' and the Mexican Ministry of Agriculture's guarantee fund, FONAGA Verde, covers first-loss credit defaults in renewable energy and biofuel generation projects.

Another Mexican development bank, NAFIN, has a guarantee program intended to support credit granting through a capital recovery guarantee for financial intermediaries. In the context of energy conservation, renewable energy, and the environment, the program offers up to 50 % selective guarantee, if certain eligibility criteria are fulfilled (Olade and UNIDO 2011; Rangel 2010).

VII. *Innovator and Aggregator*: NDBs can aggregate small-scale projects by adopting a portfolio approach when assessing the credit risk and streamlining the application process to minimize transaction costs, to encourage participation of local financial institutions (LFIs). NDBs can develop and incubate innovative and catalytic financial instruments and demonstrate to the private financial sector the potential profitability within these areas.

VIII. *International Partner*: NDBs have access to long-term sources of local and international financing as well as to nonreimbursable resources for development purposes. Multilateral and bilateral development banks, foreign export credit agencies, and also dedicated climate funds use NDBs as financial intermediaries for long-term hard currency loans as well as for the allocation and disbursement of development grants. NDBs can also blend resources at market and concessional terms from different sources.

Financiera Rural (FINRURAL), a Mexican Development Bank aimed at promoting the development of economic activities linked to the rural sector, was chosen to channel US$15 million from the Forest Investment Program (FIP), a specialized program under the Climate Investment Funds (CIF) aimed at supporting governments in their efforts to reduce emissions from deforestation and forest degradation. Through a dedicated financing line, Financiera Rural will help improve communities' access to finance for low-carbon activities in forest landscapes (IADB 2012).

IX. *Connector*: NDBs' linkages with national and international institutions and between public and private actors enable them to easily establish the connection with all of the relevant players involved in financing climate change mitigation activities and programs. NDBs also have close interactions with social and environmental organizations, as well as with civil society, and are thus often more easily accepted as partners than other lending institutions.

NDBs' Financial Instruments to Promote Private Finance and Scale Up Investments

NDBs' activities and instruments can address both demand and supply needs for finance to overcome constraints associated to the pre-investment and investment phases, thereby fostering private investments in climate-relevant projects (Smallridge et al. 2009, 2012). In particular, NDBs can apply the tools they have to:

- *Increase the demand for investments in climate-relevant projects* (pre-investment stage) by helping to address sector- and country-specific constraints, promote appropriate and stable enabling environments for investment, build awareness and capacity to analyze and structure climate-related interventions, and bring projects and companies to a state of investment readiness. The focus is to encourage, prepare, and educate project proponents to undertake the investments.

- *Provide the necessary incentives to mobilize the supply of climate-relevant investments from the private sector* (investment stage) by offering financial instruments at adequate terms and conditions for such projects and by supporting private investors and local finance institutions to understand and tackle the specific investment and financial risks and barriers. The goal is to attract capital, both debt and equity.

Typical NDBs' financial instruments to leverage climate finance (UN 2009, Smallridge et al. 2012 and NDBs' websites) include:

i. *Grants*: Grants can be used for a variety of activities in both the pre-investment and the investment stages. In the pre-investment stage, grants can finance technical assistance activities to help the project or company become investment ready. Assistance may include training or capacity building at the company level, or financing for the preparation of feasibility studies. Grants can also be more widely used for building awareness and national dialogue to strengthen and/or create environments conducive to climate-relevant investments. In the investment phase, grants can lower the interest rate of loans, extend repayment terms/grace periods, or serve as a guarantee fund for losses. These grants can be blended with NDB loans to support projects directly or to channel them via LFIs.

The Chilean CORFO (Corporación de Fomento de la Producción) has established a program supporting small and medium enterprises to optimize energy consumption. It subsidizes studies for energy efficiency audits, the implementation of energy efficiency measures, and the preparation of investment plans for submission to a funding source. CORFO covers up to 70 % of the total cost of the consultancy, with a limit of about US$10,000. It also supports renewable energy generation projects by subsidizing preliminary pre-investment studies or specialized assessments for up to 50 % of their total costs, up to a maximum of US$60,000 (CORFO.cl, Duffey 2010).

ii. *Tier 1 Loans*: Tier 1 loans are direct loans with some or all of the obligor's credit risk assumed by the NDB. The NDB thus acts like a commercial bank, extending credit directly to a project or a company. The long-term financing can be senior debt, that is, pari passu with other lenders, or subordinated debt, putting the NDB in a role of secondary creditor. In these cases, NDB financing can be blended with concessional funding (grant or low-interest loans) from international partners.

In the case of Brazil, BNDES has participated on a pari passu basis with commercial banks on a number of large wind projects to attract local and international financing. BNDES and the concerned local commercial bank participated in the transaction based on the same terms and conditions. Because such transactions are too large to be funded by a single finance institution, BNDES provides additional capacity through direct tier 1 loans (BNDES.gov.br).

iii. *Tier 2 Loans*: Tier 2 loans are loans by NDBs to a local financial institution – typically commercial banks or other financial intermediaries – for on-lending. NDBs take the credit risk of this financial institution directly, which in turn assumes the credit risk of the project.

As in the case of tier 1 loans, NDBs can blend their own resources with highly concessional resources obtained from their own government, international sources of public financing, and multilateral and bilateral institutions to improve the terms and conditions of their funding to tier 1 banks. As such, they can offer better loan terms and conditions to project developers.

COFIDE the Development Bank of Peru, uses an innovative and unusual channel for financial intermediation for taxis and buses owners that convert their vehicles into natural gas in Lima, namely, local gas stations. The loan repayments are collected via the gas station every time the vehicles are refilled. COFIDE provides tier 2 loans at concessional rates to participating banks. The usage of an existing and secure platform for loans repayment helps to improve the credit risk of individual loans, buying down transaction costs, and allowing wide-scale deployment (COFIDE.com.pe, ALIDE 2011).

iv. *Equity*: Some NDBs have a mandate to provide equity. They invest in companies and projects directly or via private equity, venture capital, or seed funds. NDBs can be in a first-loss position vis-à-vis other investors, or they can invest alongside other investors.

BANCOLDEX Capital, a subsidiary of BANCOLDEX in Colombia, addresses the market gap for venture capital resources by providing equity capital via venture funds managed by a private fund manager (e.g., Progresa Capital, a small venture capital fund focused, inter alia, in alternative energies), rather than investing directly in companies or projects (Bancoldex.com). Often, the NDB investment is seen as an anchor in a fund, drawing additional local and international capital.

v. *Guarantees*: Guarantees and related contingent liability instruments typically involve a NDB providing credit enhancement to a local finance institution, or another third-party financial intermediary providing direct funding or other investments. The NDB assumes some or all of the credit risk associated with a project that might otherwise prevent investors and/or lenders from providing funding.

   There are different types of guarantees. Those related to credit risk are most straightforward and generally better understood by market players. Traditional credit guarantees provide unconditional, irrevocable assurance to a third-party lender that principal and interest will be paid when due in the event the borrower is unable or unwilling to pay. Such guarantees normally cover less than 100 % of the borrower's payment obligations.

Many of the larger finance institutions in Peru have significant exposure and experience in financing hydropower projects and, for internal risk reasons or existing regulations, may have reached their limits in this sector. COFIDE provision of loan guarantee would allow local financial institutions to transfer the risk of financing, thereby promoting investment in the hydropower sector.

Another example is CORFO's capital guarantee and risk capital fund in support of clean energy and energy efficiency projects. This instrument was introduced in 2009 within the bank's Non-Conventional Renewable Energy program to address the specific investment risks of wind, solar, geothermal, and other renewables. In the case of capital guarantee funds, the instrument applies to both CORFO-funded projects and self-funded projects, up to a total of US$7.5 million.

vi. *Management of Funds*: In some instances, NDBs are asked to manage funds on behalf of other entities. In these cases, the NDB is not using its own resources, but rather capital provided by a third party – such as the national government or a foreign donor – managing it for a fee. As a public sector entity which acts within the financial sector, a NDB is an attractive player to take on this role, given its skills, expertise, and reliable systems.

BNDES is the manager of the Amazon Fund, created in 2008 to raise donations for nonreimbursable investments aimed to prevent, combat, and monitor deforestation in the Amazon. In addition to managing the fund, the Bank also raises funds, selects projects, and monitors their progress after they have been contracted.

The Bank is also the trustee of the Brazil National Fund on Climate Change, which was created to finance mitigation and adaptation projects and to support studies on climate change and its effects. The Fund is funded via a special tax on the profits made in the oil production chain; other contributions are collected from public, private, national, and international donors (UNDP 2011).

Table 1 NDBs' instruments to address needs to enhance effectiveness of climate finance

Phase	Climate finance needs	Climate finance activities	NDBs' financial instruments
Pre-investment phase	Technical assistance	Policy development and capacity building	Grants
	Technical assistance	Demand creation	Grants
	Financial contribution	Feasibility study/ project preparation	Partial grant or reimbursable contribution
Investment phase	LFI needs funding	Debt	Tier 2 loan market terms
	LFI needs funding/projects needs subsidized interest rates		Tier 2 loan subsidized interest
	Project needs additional capital		Tier 1 loan market terms
	Project needs additional subsidized capital		Tier 1 loan subsidized interest
	Project needs early stage cash flow room		Tier 1 longer tenor/ grace period
	LFI needs risk sharing		Guarantee
	Projects needs capital		Mezzanine debt
	Project needs equity	Equity	Equity market terms
	Project needs additional equity to draw in additional investments		Equity first-loss position

Source: Authors' elaborations based on, e.g., UN (2006), Smallridge et al. (2012), NDBs' web sites

Table 1 summarizes how NDBs' instruments can be deployed to meet the needs described both in the pre-investment and the investment stage.

During the pre-investment phase, grants or financial contributions can meet technical assistance needs, e.g., capacity building, developing expertise in the preparation and assessment of climate projects, undertaking feasibility and environmental impact studies, and designing and implementing systems for monitoring and reporting results.

During the investment phase, there are two elements in the capital structure to advance investment meeting private actors' needs: debt and equity. On the debt side, the NDB can provide a tier 2 loan if local financial institutions struggle to offer long-term debt for climate projects. Depending on the expected cash flow from the project, the loan can be at market or concessional rates. The latter are, generally, preferable for climate projects to increase the competitiveness of "clean" fuels in comparison to fossil fuels in energy generation. In other cases, the project or company might require the NDB to offer a tier 1 loan, possibly alongside commercial banks on a pari passu basis or on more generous terms, such as longer tenors or lower interest rates to improve the repayment profile of commercial bank debt.

The NDB could also provide a guarantee to bear the risks that the private sector is not willing or able to bear. Similarly, the NDB can help the equity structure by providing additional equity on equal or more favorable terms.

Overview of NDBs in the Latin American and the Caribbean Region

To bring evidence on NDBs' current level of involvement in the climate finance landscape, this section presents insights gathered from the nine (9) NDBs of the Latin American and the Caribbean region ad hoc surveyed.

The survey and dedicated discussions held (see ALIDE et al. 2012) highlighted that NDBs have been increasingly integrating climate change considerations into their core operations and become more active in financing climate change interventions. This goes hand in hand with the growing realization that NDBs have a critical role to play in channeling funds toward low-emission projects and programs.

Buchner et al. (2012) estimate that NDBs in the LAC region contributed at least USD 15.2 billion in 2011, which is about 20 % of the 2011 total commitments of the Development Finance Institutions captured by Buchner et al. (2012).

The contributions of NDBs in the LAC region are likely to grow as governments increasingly involve Development Banks to promote the structuring and financing of mitigation and adaptation projects in an effort to cover the incremental costs of these projects with funds at more favorable terms and conditions. This entails funding their participation in financing and technical assistance programs with multilateral development banks (MDBs) in order to acquire the technical and financial support needed to fulfill this new mandate (ALIDE 2011).

This is, for instance, highlighted by NAFIN's role as the trustee of the Climate Change Fund recently established by the General Climate Change Law in Mexico, as well as the initiatives under development in two Caribbean islands, Saint Lucia and Jamaica, within the adaptation-focused window of the Climate Investment Funds (CIF 2011, 2012). The engagement of these NDBs helps create the institutional framework necessary to channel the Funds' resources to local private entities (e.g., small and medium enterprises and farmers), thereby enabling them to undertake climate-resilience-building measures.

Table 2 provides an overview of the products offered by the nine NDBs surveyed. According to survey responses, some banks are tier 2 only (AFD, BANCOLDEX, COFIDE, FINDETER, and FIRA), while others (BEDE, BANDESAL, BNDES, and FINRURAL) can lend directly to projects (tier 1) or indirectly via LFIs (tier 2). Nearly half of them offer guarantees and other contingent facilities. Technical assistance is an important product for six of the nine NDBs, but only three approved financing in the past three years. Investment of equity, either directly into projects and companies or via funds, is provided by four of the nine banks.

All nine NDBs are involved in climate financing, albeit to different extents, using various instruments, and at diverse stages of "readiness" for actively promoting climate-related programs and activities. For example, AFD Paraguay has only recently become involved in this area, contributing US$220,000 in 2011 for a small reforestation project.

Table 2 Instruments offered by the surveyed Latin American NDBs

			Tier 1 loans (direct)					Equity			
NDBs	Grants/ TA	Tier 2 loans (via LFIs)	Direct equity	Equity into funds	LT investments loans	Guarantees	Other contingent facilities	ST working capital loans	Other	Management of funds	Cofinance with other funds
AFD	X	√	X	X	X	X	X	X	X	√	X
Banco del Estado (BEDE)	√	√	√	X	X	X	X	X	X	√	√
BANCOLDEX	X	√	X	X	X	√	X	X	√	X	X
BANDESAL	√	√	*	*	*	√	X	X	X	√	X
BNDES	√	√	√	√	√	X	X	√	√	√	X
COFIDE	√	√	X	X	X	X	√	X	X	√	X
Financiera Rural	√	√	√	√		√	√	√	√	√	√
FINDETER	√	√	X	X	X	X	X	X	√	√	X
FIRA	√	√	X	X	X	√	√	X	X	√	√

Source: direct reporting from the NDBs, as of April 2, 2012
Note: *TA*, technical assistance; *LT*, long term; *ST*, short term
Note: (*) since 2012, with the introduction of the Ley del sistema financiero Para el desarrollo, BANDESAL, can provide tier 1 loans. Through May of 2012, no tier 1 loans had been granted. The bank has also recently established a credit line for tier 1 renewable energy generation projects

Considering Paraguay's commitment to addressing the drivers of deforestation and forest degradation, and the recent kickoff of a dedicated UN program (UNREDD + National Program), AFD Paraguay has an increasing role to play in the forestry sector.

Other NDBs have already accessed, or are about to access, international climate funds from bilateral and multilateral entities. BANCOLDEX and FINRURAL, for example, will receive – through the IADB – international public climate funds, including US$50 million and US$15 million from the Climate Investment Funds, respectively. BANCOLDEX will receive funds from the CIF's Clean Technology Fund (CTF) to finance two programs, one to convert the public transport system in Bogotá (US$40 million) and another to promote energy efficiency measures in hotels and hospitals (US$10 million). FINRURAL, which has financing instruments in place tailored to support the rural sector, will also channel resources from the Forest Investment Program (FIP) in 2013 to local communities, through credit lines dedicated to low-carbon projects in forest landscapes.

BANDESAL and FIRA accessed bilateral funds from KfW, Germany's leading Development Bank. With this bilateral funding, BANDESAL supports "Empresa Renovable," while FIRA – under the framework of the Clean Development Mechanism (CDM) – has financed on a zero-return basis the early stages of implementation of a Programme of Activities (PoA) aimed at facilitating the capture and utilization of methane emitted from the anaerobic digestion of wastewater and/or sludge in relevant agro-industries in México. KfW also provided its expertise to develop FIRA's capacity in structuring such programs.

In addition to KfW, FIRA has established strategic alliances with several national and international specialized partners to capitalize on their expertise in the development of long-term sustainable projects while improving its knowledge about environmental issues. Among these alliances are the United Nations Environment Program, its Finance Initiative, and the Sustainable Energy Finance Alliance (UNEP-FI 2012; ALIDE 2011).

To incentivize green investments and address their specific financing needs, all nine NDBs have dedicated programs and instruments in place to finance climate-related projects. With the exception of AFD Paraguay, all offer climate finance on more favorable terms and conditions compared to their conventional credit activities. BNDES, for example, has supported renewable energy projects at interest rates 1.4 % below those practiced for coal or oil thermal plants, and with longer repayment terms (16–20 years versus 14 years for conventional plants). Moreover, BNDES maximum financing participation for renewable sources varies between 70 % and 90 %, while for coal or oil thermoelectric plants is capped at 50 % (IDFC 2012).

How NDBs Can Leverage Private Finance

By channeling national and international sources of funding into country-driven climate change mitigation activities through various financial instruments, and their comparative advantage to other intermediaries more distant from the market, the potential of NDBs to leverage public and private sector resources appears significant.

To our best knowledge, no published work exists so far on the leverage potential of NDBs. It is in fact complex to aggregate the true volume of financial flows from these institutions to private investment in climate-relevant activities, as also noted in IMF (2011). Also, while there is broad agreement on the need to leverage private sector involvement (see, e.g., IMF 2011; AGF 2010), there is no single, universally applicable definition of this term, or methodology to calculate leverage ratios. There is uncertainty about how best to quantify its extent, as this term has different meanings in different contexts and to different people (Buchner et al. 2011; Brown and Jacobs 2011). Furthermore, the leverage factor is not only dependent on the instruments being used, but can vary considerably according to the barriers being addressed, the country/region where the investment takes place, and the specific project characteristics (see Brown and Jacobs 2011). The nature of the intermediary delivering climate finance also impacts the level of leverage potentially achieved.

In financial terms, leverage refers to the ratio of equity to a blend of debt. Financial institutions such as MDBs measure it as the ratio of public to private cofinancing, as they aim to understand and demonstrate the multiplier effect generated by their contributions.

Given that private finance represents the lion's share of the climate finance landscape (Buchner et al. 2011, 2012) and that it is the source that needs to be incentivized and scaled up to achieve the required funding to finance climate change mitigation and adaptation interventions, this study defines leverage as "the process by which private sector capital is 'crowded-in' as a result of the use of public sector finance, and of the financial instruments deployed by public financial intermediaries." This definition builds on Brown and Jacobs (2011).

It is difficult to estimate a specific and sound leverage ratio for NDBs. Few of them consistently track and measure the amount of private sector capital mobilized as a consequence of their activities. This is even more complex in the context of climate finance. However, a look at their advantages and disadvantages compared to those of MDBs indicates the scale of the catalytic effect generated by NDBs. Case studies analysis can also help to shed light into this.

NDBs have a variety of financial instruments at their disposal to facilitate low-emission, climate-resilient investments, many of which are the same as those available to MDBs, but the conditions under which they are provided are different. Building on the methodology developed by the United Nations' High-Level Advisory Group on Climate Change Financing (AGF 2010) to calculate the potential leverage effect exerted by public financing instruments used by MDBs, the study derives the leverage effect that could potentially be exerted by NDBs in LAC.

Table 3 compares the MDBs and NDBs leverage factors of various financing instruments, some of which are generally available to NDBs, but for which no analysis on the use of them by MDBs has been conducted (and therefore N/A is listed in the MDBs column). The leverage factor assumes that the only private capital directly mobilized comes from other financiers, such as local financial institutions. The leveraging potential triggered by a combined set of instruments has not been considered.

Table 3 Comparison of MDBs and NDBs leverage factor

Category of instrument		MDBs theoretical leverage factor	NDBs theoretical leverage factor
Tier 1	Non-concessional debt	2–5 x	2–5 x
	Debt financed via grants	8–10 x	8–10 x
Tier 2	Non-concessional debt	N/A	1 x
	Debt financed via grants	N/A	4–8 x
Tier 1	Direct equity	8–10 x	12–15 x
	Equity financed via grants	20 x	20 x
Tier 2	Direct equity	N/A	12–15 x
	Equity financed via grants	N/A	N/A
	Guarantees at non-concessional rates	N/A	4–8 x
	Guarantees financed via grants	20 x	25 x

Source: Adapted from AGF 2010; Brown and Jacobs 2011
N/A, no data available

Tier 1 loans (both concessional and non-concessional) apply the same leverage factor that has been proposed for MDBs, as there is no reason to believe that the ability of a NDB to draw private capital to projects is any better or worse than that of a MDB. MDBs will have a better credit rating for foreign currency loans, which may entice foreign banks to lend alongside of them. However, for local finance institutions working in local currency, NDBs could have a similar level of leverage.

In terms of equity, leverage is assumed to be higher for NDBs than MDBs. NDBs typically focus on local funds and often act as anchor investors. These funds will then invest in a number of smaller projects in early stages of development. NDBs can draw other institutional investors into the funds, and these, in turn, can draw coinvestors into projects and companies. MDBs tend to work alongside offshore equity providers and can opt for direct investments in larger and relatively more established projects. Sometimes, MDBs will also invest in funds, but the rationale is that local investors will rely more on NDBs to provide a signal or a demonstration effect.

As for guarantees, the leverage factor depends on the type of guarantee offered, but in all cases it is reasonable to expect that a NDB's leverage factor exceeds that of a MDB (i.e., NDB guarantees will be less likely to be called; thus, less capital needs to be allocated) for two main reasons: (a) the NDB can more readily anticipate – and possibly even influence – host country factors, which could impact, directly or indirectly, the likelihood of a guarantee being called, and (b) by operating directly and solely in the host country, the NDB intimately understands local market conditions and the potential impact such conditions may have on the credit quality or commercial performance of a climate-related project.

NDBs' proximity to local finance institutions and local private actors thus suggests that their ability to leverage is equal to or potentially better than that of MDBs for the same instruments.

Leverage Effect by LAC NDBs

At the end of 2011, NDBs in the LAC region had outstanding assets of nearly US$1 trillion and a capital base of US$100 billion, which combined with their capacity to leverage resources makes them unique players in scaling up private investments for climate change mitigation. Table 4 shows the nine NDBs sampled and the size of their capital, assets, and annual business volume for 2009–2011.

The banks analyzed in Table 4 represent over one-third of the LAC region's NDB assets and capital. Five out of the nine banks sampled have systems in place to track how much private finance is being leveraged by their operations, BNDES, COFIDE, FINRURAL, FINDETER, and FIRA, but the majority lack system for specifically monitoring, reporting, and verifying climate investments.

The information provided suggests that these institutions look at leverage in terms of cofinancing. For instance, BNDES reports an average multiplier of about 1.4 times its own contributions for its general operations (based on data from 2009 to 2011). Following the same approach, COFIDE estimates that its tier 2 loans mobilize an additional 20–30 % more from private sources. Commercial banks generally finance up to 60 % of project costs, while the remainder has to come from other private capital. FIRA estimates the relative share of their lending to individual borrowers to be, on average, 54 % of their entire portfolio (over 2009–2011). An average of 31 % has to come from commercial banks, while the remaining from other sources, including other development banks and external sources.

Table 4 Capital, assets, and annual business volume of the sampled NDBs, 2009–2011 (in US$ millions)

NDBs US$ million	Capital base 2011	Total assets 2011	Annual business volumes (approvals) 2009	 2010	 2011
AFD Paraguay	101	275	43	82	110
Banco del Estado Ecuador	247	1,239	741	885	927
BANCOLDEX Colombia	694	3,069	2,449	2,677	2,828
BANDESAL El Salvador	198	575	213	212	291
BNDES Brazil	32,526	333,099	72,186	96,322	82,716
COFIDE Peru	804	2,005	824	1,039	1,570
Financiera Rural Mexico	2,128	2,174	1,854	1,738	1,928
FINDETER Colombia	0.444	3,380	1,029	1,046	1,368
FIRA Mexico	4,687	7,104	7,986	8,331	7,935

Source: direct reporting from the NDBs, as of April 2012

Case Study: NAFIN's Role in Leveraging International and National Public Climate Finance

To shed light on the leverage potential possibly exerted by NDBs, this case study presents how international public climate finance channeled through NDBs can be deployed to mobilize private finance toward public objectives.

Nacional Financiera (NAFIN) has become a key partner in the implementation of the Mexican government's low-carbon development strategies and for accelerating private investments in low-carbon technologies in the country.

Engaging the private sector in low-carbon financing has been a particular challenge in Mexico where, in addition to sector-specific issues (e.g., high investment needs, technology-specific risks, banks' lack of relevant expertise, and high risk aversion), access to credit and the relatively underdeveloped size of the financial sector are major structural barriers in the local economy (IADB 2011a, b). These factors result in a lack of adequate financial instruments to support the renewable energy sector, which results in high interest rates, high transaction costs, a need for large amounts of collateral, and an unexploited renewable energy potential.

Within Mexico's Country Investment Plan, endorsed by the Clean Technology Fund Trust Fund Committee in 2011, these barriers were tackled through international financial and nonfinancial support to structure financing solutions such as the Renewable Energy Financing Facility (REFF) (IADB 2011a, b). This facility was established within NAFIN to fill the financing gap through the provision of: (a) direct loans to project developers, with maturities in the 10–15-year range, and fixed interest rates, to finance the construction of new renewable energy projects (final terms and conditions for borrowers will depend on the characteristics of the project, its internal rate of return, and its risk profile), and (b) contingent credit lines to cover transitory cash flow shortages during the project life cycle (e.g., due to lower than expected energy generation, energy demand, or prices) up to the volume needed to service senior debt (IADB 2011b).

NAFIN was chosen because of its privileged position for channeling – directly or indirectly – international resources, along with its own resources, to local players (i.e., other financial intermediaries or project developers), ultimately enhancing the overall leverage impact of the international funds. The program aimed to leverage the US$70 million of the Clean Technology Fund concessional resources, with at least US$70 million that would come from IADB cofinancing from an existing credit line and a similar amount from NAFIN's own resources (see Fig. 2).

NAFIN would then leverage the overall total (minimum) amount of the US$210 million facility at the project level by catalyzing private capital. Since a single project is not entitled to receive more than US$10 million of the resources of the Clean Technology Fund, and no more than 50 % of its total investment needs from the facility, these conditions aim to maximize the leverage effect as well as the number of projects financed. The IADB estimates that at least US$1.19 billion–US $1.54 billion will have to be mobilized to cover the investment costs of the projects

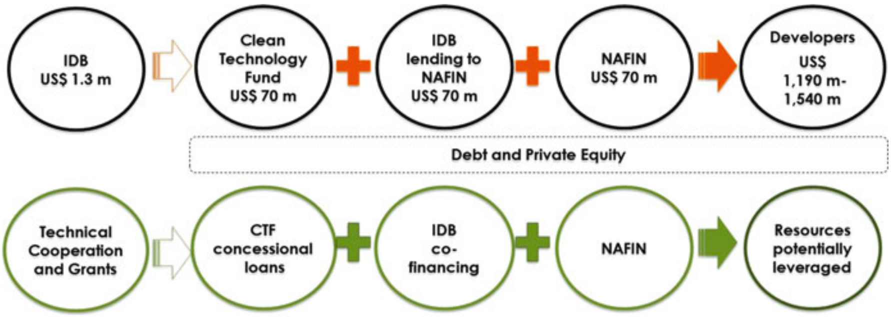

Fig. 2 The estimated leveraging effect of CTF-REFF and NAFIN (source: Authors' elaboration based on IADB (2011a, b))

financed by the facility (IADB 2011a, b). This amount is estimated considering a total 1,000 MW of installed generation capacity and investment costs of US$2–2.5 million per MW, assuming an equity to debt ratio of 30/70 (IADB 2011b).

NAFIN is key to make this happen, as it is in charge of project selection, demand stimulation, and the structuring of financial packages appealing to local project developers and tailored to their needs. The risk-sharing arrangements put in place between NAFIN and borrowers will be critical for unlocking financing, as developers depend on the off-takers' credit qualifications.

NAFIN was a natural partner for the IADB for the execution of this program, given the long relationship between the two and the fact that NAFIN supports private sponsors in the financing of projects with climate change mitigation objectives. NAFIN has proven to be a solvent institution with adequate risk management systems and practices in place. NAFIN has established a sustainable Project Directorate, a unit dedicated to supporting climate-related projects, which received technical assistance from the World Bank. NAFIN has already experience in structuring the financing of wind energy projects, which will likely constitute the majority of the projects supported under the REFF. In fact, it has already supported the financing of the EURUS and the Piedra Larga wind farms in the region of Oaxaca, which are also part of the overall CTF investment plan.

By executing the REFF program, NAFIN's capacity in the preparation, assessment, evaluation, and monitoring of risks in this type of project is expected to be further strengthened. In turn, this capacity and know-how can also then be extended to the local banking system. Local finance institutions that take part in projects will develop their own capacity, familiarize themselves with the risk management and financing requirements of these projects, and develop the institutional capacity required to handle them. This can help to unlock their financing potential ultimately boosting renewable energy investments in the country by exploiting their ability to reach a wide group of interested recipients.

Conclusions

To support the global transition toward a low-carbon, climate-resilient future, there is a pressing need to scale up investments in climate change mitigation. As public financial resources cannot finance this transition alone, unlocking private capital is essential. International and national public funds are critical to mobilize private climate finance by taking on the classes of risks and costs that the private market will not bear.

A number of key features unique to NDBs make them well placed to play a significant role in supporting the transition by acting as intermediaries or sources of climate finance. Their proximity, knowledge, and long-standing relationship with the private sector put them in a privileged position for accessing local financial markets and understanding local barriers to investment. NDBs' services and range of instruments can help to tackle the specific investment and financial obstacles that prevent private actors from engaging in low-carbon projects, thereby promoting private investments. The study shows that their ability to leverage is equal to or potentially better than that of MDBs for the same instruments.

Nevertheless, many NDBs are at different stages of the learning curve for supporting climate finance efforts. Many require technical assistance to develop the capacity needed to assess, analyze, and structure green investment projects.

This was also highlighted by the result of the survey conducted with nine NDBs operating in the LAC region and the discussions had in dedicated forum (see ALIDE et al. 2012). The survey, in particular, highlighted that NDBs in this region are already piloting the use of dedicated instruments in support of climate change mitigation investment, both at the investment and pre-investment stage, and have significant potential for leveraging national and international public and private resources. At the end of 2011, surveyed NDBs in the region had outstanding assets of nearly US$1 trillion and a capital base of US$100 billion that, combined with their capacity to leverage resources, makes them unique players in scaling up private investments for climate change mitigation.

However, the following actions are deemed necessary to enable these players to more effectively scale up private investments:

I. *Enhance the dialogue between national policymakers and NDBs to promote an active role of NDBs in delivering international climate finance*. While in several countries such as Brazil NDBs have a clear government mandate to promote national climate change mitigation programs, most lack such mandate and are rarely involved in the design of such programs. Their advice is also rarely considered for the design and functioning of new climate finance mechanisms such as the Green Climate Fund. To fully harness the potential of NDBs in climate finance, there is the need for considering NDBs' experience and advice for the design and functioning of new climate finance mechanisms, and further use NDBs as vehicles to manage and channel climate finance resources.

II. *Encourage NDBs to develop readiness strategies for international climate finance mobilization and intermediation*. NDBs are at distinct stages of institutional development to operate in new areas of financial practice, such as climate finance. While some like BNDES already have the capacity to be active in climate finance, others still need to develop and strengthen their capabilities in this area. To strengthen NDBs' participation in climate finance, a clear mandate and support from their respective governments, as well as by increasing interactions with relatively more developed regional, national, and international financial institutions such as MDBs. To become credible and reliable intermediaries and access international climate funds, they must also develop the capacity for monitoring, reporting, and verifying climate investments and their environmental benefits. This requires NDBs to develop considerable capacity.

III. *Build knowledge about best practices of NDBs in climate finance.* A better understanding of effective funding sources and channels and the catalytic potential of different instruments can provide lessons to the international climate finance community on what works and what does not, informing the design of existing and emerging financing mechanisms, and helping governments to spend their limited financial resources more effectively. Given the ongoing efforts in the design of the Green Climate Fund, there is a window of opportunity for NDBs to feed lessons from their own financing practices on the ground and experiences with the private sector, thus influencing the future of climate finance.

Assigning NDBs a key role in mobilizing and intermediating international climate finance increases the potential to achieve climate and development goals. Targeted efforts to address a number of issues and themes could substantially improve the capacity of NDBs to make game-changing contributions to the international climate finance landscape.

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Water, Food, and Energy Nexus in South Asia: Implications for Adaption to Climate Change

Golam Rasul and Bikash Sharma

Contents

Abstract

Adaptation to climate change has received increased attention in recent years in the academic and development discourse. Effective adaptation to climate change requires the efficient use of land, water, energy, and other vital resources, together with coordinated efforts to minimize trade-offs and maximize synergies. The concept of water, energy, and food nexus is considered to be an effective mechanism for enhancing resource use efficiency, minimizing trade-offs, and maximizing synergies in resource use. However, as in many developing countries, the policy process in the countries of South Asia generally follows a

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sectoral approach that does not take into account the interconnections and interdependence among the three sectors. In designing effective adaptation strategies, it is critical to understand the linkages between the nexus perspective and adaptation to climate change. This paper seeks to increase understanding of the interlinkages in the water, energy, and food nexus, explains why it is important to consider this nexus in the context of adaptation responses, and argues that focusing on trade-offs and synergies using a nexus approach could facilitate greater climate change adaptation and help ensure food, water, and energy security by enhancing resource use efficiency and encouraging greater policy coherence. The paper provides a conceptual framework for considering the nexus approach in relation to climate change adaptation, discusses the potential synergies, and finally offers a broader framework and reform measures for making adaptation responses more effective and sustainable.

Keywords
Water-food-energy nexus • Adaptation to climate change • South Asia • Policy coherence • Trade-offs • Synergies

Why is Nexus-Based Adaptation Important?

Climate change is already threatening both the development process and the basic elements of life, such as access to water, energy, food production, and the environment, around the world and especially in developing countries. With 70 % of the expected global population of 9.2 billion people living in cities by 2050, demands for water, energy, and food will increase exponentially. The demand for food is expected to rise by 35 % by 2030 and for water and energy by 40 % each (Hoff 2011). Currently, some 1.2 billion people live in regions with insufficient water to meet human needs, and at least 1.5 billion are without access to modern forms of energy. By 2040, one-third of the world's population will live in areas of water stress (Hajkowicz et al. 2012). Competition for land for food and energy is expected to increase. In 2008, about 100 million tons of cereals (4.7 % of global cereal production) were used in the production of biofuels. Global energy use has approximately doubled over the last 30 years, and by 2040 the demand is likely to grow by more than half again. Thus, competition for land for biofuels is likely to increase further. There is growing evidence that the atmosphere will continue to warm throughout the twenty-first century, which will affect water availability, food production, and energy use and require effective adaptation.

The global community is looking for new approaches and solutions to adaptation to climate change, as well as to meeting development challenges, such as ensuring water, energy, and food security that are critical for human survival and sustainable well-being. Water, energy, and food are all subject to rapidly growing global demand and all face resource constraints, while billions of people lack sufficient access to them (Bazilian et al. 2011). The ongoing depletion of these strategic resources as a result of unsustainable consumption and production patterns is constraining future economic growth and social progress and threatening the very basis of human survival, and the situation is likely to worsen in the face of increased demands. The Rio + 20 Declaration “The Future We Want” stresses the need for balanced integration of economic, social, and environmental concerns in economic development and also highlights the urgent need to address food, water, and energy security in such a manner as to reduce the adverse impacts on human and natural systems as one of the greatest challenges facing humanity.

Meeting this challenge has emerged as a top priority on the national and international development agenda. Mitigation and adaptation are complementary components of a response strategy to climate change, aimed at reducing the extent as well as increasing the resilience to change. Adaptation is critically important in developing countries, where large numbers of people depend on climate-sensitive sectors such as agriculture, forestry, and fisheries; have limited resources and capacity; and live in climate-vulnerable settings such as mountains and coastal areas (WRI 2011, Shrestha and Aryal 2011). The goal of adaptation is to reduce vulnerability to both climatic and non-climatic changes; thus, it is closely linked with the sustainable use and management of water, energy, and food, all of which are vital for sustainable development.

The production and consumption of water, energy, and food are closely interlinked, forming a nexus, with changes in any one component likely to have a marked impact on the others. However, they still tend to be treated as separate issues, both in regular development planning and in planning for adaptation. The failure to recognize the close linkages can result in counterproductive actions that threaten the success and sustainability of planned interventions, which is particularly problematic in adaptation, where changes are being made to enable survival in a future changed situation for which there is no guiding experience. At the same time, recognition of the nexus offers possibilities for planning to be made more effective. There are several compelling reasons for pursuing nexus-based adaptation as an effective strategy to meet future challenges.

Promoting Synergy and Co-benefits: Although interest in adaptation to climate change impacts has surged in recent years, the focus has remained sectoral. The role of the water-food-energy nexus in addressing the competing demands of, and facilitating, adaptation and development has not yet been fully recognized. Historically, most adaptation plans, including the National Adaptation Programmes of Action (NAPAs), have been prepared to meet sectoral goals. They generally focus on sectoral and project-based activities, without adequate consideration, or coordination, of cross-sectoral interactions among key climate-sensitive sectors, such as water, energy, and food, which can be used to minimize trade-offs and promote synergy and co-benefits.

Overcoming Maladaptation Practices: Sectoral adaptation strategies can increase vulnerability or undermine net resilience by decreasing capacity or increasing risks in another place or sector, resulting in maladaptation practices (Walker et al. 2006; Urwin and Jordan 2008; Barnett and O’Neill 2010). For example, in China, excessive use of pesticides in food production has had a negative impact on health costing an estimated USD 1.4 billion per year and has adversely affected farm and off-farm biodiversity (Norse et al. 2001), which in turn has negatively affected food production. Similarly, subsidies for groundwater extraction, provided by many South Asian countries to cope with surface-water shortages and uncertainty in water availability, have led to overexploitation of groundwater, wastage of scarce water resources, and increased demand for energy for pumping, ultimately undermining food and energy security. Baluchistan, an arid region of Pakistan, is now growing apples and other fruit through groundwater irrigation which requires huge amounts of energy, while the country faces crippling shortages of energy for other activities (Mustafa and Qazi 2007; Khair 2013). Overcoming these problems is not possible without taking a nexus perspective to develop integrated solutions.

Ensuring Policy Coherence and Coordination: The prevailing approaches see adaptation largely as a local issue with a community or ecosystem focus (Huq and Reid 2004) and ignore the role of the national, regional, and global policies and institutions which shape adaptation options and choices. Local adaptation approaches often prove unsustainable owing to inadequate institutional support (Agrawal 2010). Climate change brings multiple stresses, and adaptation requires comprehensive and integrated approaches with coordination between different sectors and at different scales: local, national, and regional. As water, energy, and food are critical for human survival and sustainable well-being, managing these vital resources sustainably requires a nexus perspective.

Addressing Planetary Boundary and Resource Scarcity: Ongoing global climate change, the rapidly increasing population, urbanization, globalization, and aspirations for better living standards are already posing a challenge to planetary sustainability, pushing the planet beyond its carrying capacity. Climate change and anthropogenic pressures have exacerbated the pressure on water, energy, and food (Rockstrom et al. 2009). All three sectors are both highly vulnerable to climate change and contribute heavily to that change through their greenhouse gas emissions (Howells et al. 2013; Calow et al. 2011). Adaptation is therefore intrinsically linked to water, energy, and food security. The nexus approach provides a framework for addressing competition for resources through enhancing resource use efficiency. Although the likely impacts of climate change on water, energy, and food production have raised serious concerns and been emphasized in the pursuit of appropriate adaptation measures, the links among water, energy, and food, and the role of this nexus in sustainable adaptation, have not yet been well researched. Failure to consider the nexus of water, energy, and food in resource assessments and policy making has led to contradictory strategies and inefficient use of resources (Howells et al. 2013).

The Need for Urgent Action

With large populations, limited land resources, and growing water stress, South Asian countries face the common challenge of how to grow more food with the same or less land, less water, and increased energy prices. Rice and wheat, the staple foods in the subregion, require huge amounts of water and energy. Efficient and coordinated management of water, energy, and food is critical for adaptation and mitigation to climate change in the region (Rasul 2014).

Organization of the Chapter

Understanding the role of the water, energy, and food nexus in adaptation is an essential basis for designing effective adaptation policies and strategies. This chapter, using South Asia as an example, argues that in the developing world, focusing on the trade-offs and synergies of the water, energy, and food nexus is a potential strategy for integrated and efficient resource management and for adaptation to address future challenges in a systematic way. Following this introductory section, section "Conceptualizing Climate Change Adaptation and the Water, Energy, and Food Nexus" provides an overview of the concepts of climate change adaptation and the water, energy, and food nexus; section "Challenges of Food, Water, and Energy Security and Adaptation to Climate Change in South Asia" discusses the interrelated challenges of water, energy, and food security in the South Asian region and the implications for adaptation to climate change; section "Synergies in the Water, Energy, and Food Nexus and Adaptation Strategies" provides a more detailed discussion of the synergies between water, energy, and food and the way in which the nexus perspective can help in adaptation to climate change; and finally, section "Towards a Nexus-Based Framework for Sustainable Adaptation" offers a broader framework and reform measures for making adaptation responses more effective and sustainable. The study relies predominantly on information drawn from secondary sources, including books, reports, and journal articles. Some information has been drawn from the research experience of the International Centre for Integrated Mountain Development (ICIMOD) in the Hindu Kush Himalayan (HKH) region over the past 30 years, as well as the authors' own research experience in the region.

Conceptualizing Climate Change Adaptation and the Water, Energy, and Food Nexus

Although a growing body of literature is emerging on both adaptation to climate change and the water, energy, and food nexus, the linkage between the two is rarely explored or articulated in the policy-program-action continuum. This section briefly examines these concepts and their linkages.

Evolving Approaches to Adaptation to Climate Change

Adaptation has received increased attention in recent years in the academic and development discourse. Different scholars define adaptation in different ways based on their professional interests (e.g., Adger et al. 2005; Doria et al. 2009; Smit and Wandel 2006; OECD 2009). In terms of climate change, adaptation has been defined as the process or adjustments through which people reduce the adverse effects of climate on their health and well-being and take advantage of the opportunities that their climatic environment provides (IPCC 2007). Adaptive capacity

Table 1 Evolving approaches to adaptation

Feature	1990s	2000s	2010s
Overall objective	Reducing climate risks and impacts	Reducing climate risks and uncertainties	Reducing climate risks and impacts with socioeconomic improvements Mainstreaming climate change adaptation into development
Scope	Sector-based approach, location specific	Sector-based approach, but adaptation mainstreamed into sectoral planning	Trans-sector and transboundary approaches started
Focus of activities	Protective: coping strategies, protection of those most vulnerable to climate risks and with low levels of adaptive capacity	Preventive: coping strategies, prevention of damaging strategies arising from risks to climate-sensitive livelihoods	Transformative: building adaptive capacity, transforming social relations to combat discrimination and underlying social and political vulnerability
Activities	Activities seek to address impacts exclusively associated with climate change: provision of social services; social transfers (food/cash), including safety nets	Managing climate risks: activities seek to incorporate climate-related information into decision-making	Building response capacities: activities seek to build robust systems for problem solving Addressing the drivers of vulnerability: activities seek to reduce poverty and other non-climatic stressors that make people vulnerable

Sources: Adapted from Davies et al. (2013), Calow et al. (2011)

and vulnerability are thus important concepts for understanding adaptation. While vulnerability can be seen as the context in which adaptation takes place, adaptive capacity is the ability or potential of a system to respond successfully to climate variability and change, in order to reduce adverse impacts and take advantage of new opportunities (World Bank 2010).

The concept of adaptation continues to evolve, however, and its focus is gradually changing from simply responding to the impacts of climate change to addressing the underlying factors that cause vulnerability. More specifically, approaches to adaptation have evolved from the initial infrastructure-based interventions to a more development-oriented approach based on building broader resilience to climate hazards by addressing the underlying causes of vulnerability rather than simply responding to the symptoms (Calow et al. 2011; Davies et al. 2013). Trans-sector and transboundary considerations, however, are only just emerging. Table 1 shows how adaptation approaches have evolved over the past two decades in terms of assessment of risks, mainstreaming, focus, and scope. In the 1990s, the focus was on assessment of the climate risks and aimed at reducing climate impacts using a locally specific sectoral approach. In the 2000s, the theory of adaptation, including the notion of mainstreaming, gained momentum faster than policy and practice, although the sector-based approach still dominated in mainstreaming. In the current decade, the emphasis has shifted, with adaptation linked more to sustainable development. There has been a shift away from sectoral approaches and an emerging emphasis on cross-sectoral and transboundary approaches, for example, focusing on river basins.

Broadly, there are two distinct perspectives on how to approach adaptation in developing country contexts. The first focuses on reducing climate change impacts. The second focuses on reducing vulnerability by addressing not only climate change but also other drivers of vulnerability and poverty such as gender and social equity, as well as other structural factors hindering long-term sustainable development.

In practice, most interventions fall somewhere between these two extremes. The development-oriented approach emerged based on the underlying premise that people are vulnerable not only to climate change but also to a range of other stresses, depending on access to resources and other socio-environmental circumstances shaped by political and economic processes (Kelly and Adger 2000; O'Brien et al. 2004). Technological measures designed to adapt to specific changes in climate may fail to address the issues local people consider most urgent, such as access to water, food, and energy and livelihood security.

It is increasingly recognized that successful adaptation will require interventions that address the full spectrum of challenges, including underlying causes of vulnerability, in the context of other theories of risk and development. As pointed out by Schipper (2007), "mainstreaming will not be effective if existing development trajectories are inconsistent with the objectives of adaptation. It is vulnerability reduction that should be integrated into development policy, rather than the creation of explicit adaptation strategies. In this sense, focusing on adaptation before aligning development processes through the creation of enabling conditions for adaptation is like putting the cart before the horse."

Concept of Sustainable Adaptation

Debates on climate change adaptation have taken place largely outside the broader discourse on sustainable development (Bizikova et al. 2013). Sustainable development has only been included as a theme by the Intergovernmental Panel on Climate Change (IPCC) since the third assessment (Munasinghe and Swart 2000), and little attention has been paid to the identifying principles that create synergies between adaptation and sustainable development. Climate change adaptation can be made more relevant to policy by contextualizing it within a sustainable development framework (Robinson and Herbert 2001). Eriksen et al. (2011) define sustainable adaptation as "a set of actions that contribute to socially and environmentally sustainable development pathways, including social justice and environmental integrity. It considers the wider effects of adaptive responses on other groups, places, and socio-ecological systems, both in the present and in the future." According to Doria et al. (2009, p. 815), "Successful adaptation is that adaptation that generates net benefits for the adapting party, in both the short- and long-term, without causing net loss of welfare for the wider society." A sustainable adaptation process requires adjustments in policies, institutions, and attitudes to establish enabling conditions for sustainable development through reduction of vulnerability, while at the same time overcoming factors that cause vulnerability to climate change. Considering that not every adaptation intervention reduces poverty and inequality (and some poverty reduction measures may aggravate vulnerability), sustainable adaptation measures need to specifically target the nexus between vulnerability and poverty (Eriksen and O'Brien 2007; Eriksen et al. 2011) while emphasizing transitions to low-carbon economies (Winkler and Marquand 2009).

Principles of Sustainable Adaptation

Although as yet there is no framework or set of principles for sustainable adaptation agreed by all stakeholders, certain key principles can be discerned:

- Adaptation is an integral part of sustainable development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs, grow, and adapt.
- Adaptation must be addressed in a comprehensive and intersectoral manner, as part of overall development.
- Adaptation of one sector or one community should not lead to a net loss of welfare for the wider society.
- Adaptation responses and mechanisms should be sensitive to the needs of local communities and their resources, knowledge, and culture.

The Concept of the Food, Water, and Energy Nexus

The discourse on food, water, and energy security is driven by the growing pressure on natural resources. The demand for food, water, and energy is growing steadily, but the resources required to generate them are limited and in many cases dwindling (Rockström et al. 2009; State of the Planet Declaration 2012). The interdependencies among water, energy, and food are numerous and multidimensional; this relationship is often called the food, water, and energy nexus (although the order of the components may vary). Although the discourse on this nexus has been gaining currency (Marsh and Sharma 2007; Hoff 2011; Hussey and Pittock 2012), how the concept can be applied to ensure food, water, and energy security is not yet clearly understood. Understanding the different interfaces in the food, water, and energy nexus is critical for taking sustainable adaptation action to address food, water, and energy security.

Complex Interrelationships

- *Water for food and energy*: Water plays a vital role in food and energy production and in sustaining the ecosystems which support agriculture and other economic activities that are critical for achieving food security (Molden 2007; Hellegers et al. 2008).

- *Energy for food and water:* Energy is required for food production (especially irrigation) and for water supply, including extraction, purification, and distribution of water (Nonhebel 2005; Bazilian et al. 2011). About 7 % of the world's commercial energy production is used for managing the freshwater supply (Khan and Hanjra 2009). Agriculture accounted for almost 21 % of the total power consumption in India (Kumar et al. 2012).
- *Agriculture and land for energy and water:* Agriculture has a dual role as an energy user and as an energy supplier in the form of bioenergy. Sustainable agricultural practices such as actions to avoid land loss or degradation save water by increasing soil water storage and groundwater recharge. They also save energy, for example, by reducing the use of energy-intensive fertilizers. Agriculture and food production have a further impact on the water sector through their effects on land condition, runoff, groundwater discharge, water quality, and availability of water and land for other purposes such as natural habitat (Alauddin and Quiggin 2008).

The relationships among food, energy, and water are dynamic. Actions in one area usually have impacts on one or both of the others, with profound economic, environmental, and social implications. Indeed, the security of one sector often cannot be achieved without undermining security in another sector (Newell et al. 2011). The environmental footprints associated with increased water and energy use for food production impose external costs to water and ecosystems, thus threatening the sustainability and resilience of global water and food systems (Khan and Hanjra 2009).

The nexus approach aims to systematize the interconnections and provide tools to assess the use of all resources (Hermann et al. 2012). It is a system-wise approach; it recognizes the inherent interdependencies of the food, water, and energy sectors for resource use, seeks to optimize the trade-offs and synergies, and recognizes the social and environmental consequences (Bazilian et al. 2011; Prasad et al. 2012). Understanding the linkages within the food, energy, and water nexus can provide opportunities to increase resource use efficiency and enhance cooperation and policy coherence among the three sectors. For example, sustainable agricultural practices, such as those designed to prevent land degradation, save water and energy by increasing water storage in the soil and groundwater recharge and by reducing the use of energy-intensive fertilizers. The nexus perspective should help to promote interdisciplinary and mutually beneficial actions (Scott et al. 2011). It can contribute to meeting the future needs of the global population, particularly those who do not have access to safe drinking water and modern energy (Marsh 2008). From this perspective, identification of crucial interactions, conflicting demands, and potential synergies in the water, energy, and food nexus can be a powerful entry point for achieving sustainable adaptation.

Key Principles of the Nexus Approach

The nexus approach is centered around core principles of efficiency, equity, and sustainability; the fundamentals of the approach can be summarized as follows:

- Understand the interdependence of subsystems within a system across space and time, and focus on system efficiency (using a systems-based approach to natural resource policies and regulations) rather than the productivity of individual sectors to provide integrated solutions that contribute to water, energy, and food security and sustainable development.
- Recognize the interdependence between water, energy, and food, and promote the wise development and efficient use of these resources in an environmentally responsible manner.
- Identify crucial interactions, conflicting demands, and potential synergies to minimize trade-offs and maximize synergies across sectors, and encourage mutually beneficial responses that enhance the potential for cooperation between and among all sectors.
- Ensure policy coherence and coordination across sectors to build synergies and generate co-benefits to produce more with less, while reducing loss and waste in the spirit of the 3Rs principle – recharge, retain, and reuse – and contributing to long-term sustainability with limited environmental impact.
- Value the natural capital of land, water, energy, and ecosystems to support the transition to sustainability.

Interfaces Between the Water, Energy, and Food Nexus and Adaptation Strategies

The water, energy, and food nexus and adaptation responses are interlinked in numerous ways. Understanding the interlinkages is critically important for policy makers in devising sustainable adaptation strategies. Table 2 shows the links between the adaptation response and nexus approaches, which share many common features, while indicating complementarities and co-benefits from nexus-based adaptation.

Challenges of Food, Water, and Energy Security and Adaptation to Climate Change in South Asia

South Asia is one of the most dynamic regions of the world in terms of population growth, economic progress, urbanization, and industrialization. The demographic, economic, and environmental changes in South Asia have increased the demand for resources, including food, water, and energy, and intensified their use, which has serious implications for adaptation strategies to ensure food, water, and energy security in the region.

The population of South Asia almost tripled from 588 million to 1.6 billion in the half century from the late 1950s to 2010 and is expected to reach 2.2 billion by 2025. With high population growth and industrial development, cereal demand is projected to rise to 476 million tons by 2025, compared to 241 million tons in 2000 (FAO 2011). But this higher agricultural production has to come from the same

Table 2 Complementarities and co-benefits from nexus-based adaptation

Key characteristic	Nexus approach	Climate change adaptation	Complementarities and co-benefits from nexus-based adaptation
Goal	Ensure efficient use of available resources to support transition to sustainability	Build resilience and enhance adaptive capacities against climate and other risks	Understanding adaptation to climate change is critical for addressing nexus challenges and efficient use of resources is critical for effective adaptation
Core principles	Minimize resource waste and maximize economic efficiency, while accelerating the sustainable supply	Reduce vulnerability by managing climate risks and building response capacity	Since resource scarcity often increases people's vulnerability, the nexus approach may contribute to facilitating adaptation and vice versa
Main focus	Provide integrated solutions that contribute to sustainable development	Minimize shock, risks, and vulnerability and address impacts and risks associated with climate change	Understanding vulnerability to climate change is crucial for assessing nexus challenges; equally integrated nexus solutions can contribute to reducing vulnerability and poverty
Broad strategies	Policy integration, harmonization, and governance to build synergies and generate co-benefits across sectors in a sustainable way	Addressing the drivers of vulnerability to climate change in specific sectors through building adaptive capacity and resilience	Cross-sectoral nexus analysis identifies trade-offs and synergies and integrates policy implementation; diversification increases resilience; the nexus strategy is critical for integration of climate adaptation and mitigation, while broadening the scope to address poverty-vulnerability linkages

amount of land and may be even from less land, because of competing uses arising from population growth, urbanization, and industrialization. Per capita food consumption has remained stagnant in many parts of South Asia in recent years, despite impressive growth in per capita income (Alagh 2010). Low levels of consumption have contributed to persistent hunger and malnutrition (Dev and Sharma 2010) in South Asia.

Increasingly Water- and Energy-Intensive Food Production in the Face of Water and Energy Scarcity

Agriculture consumes about 90 % of the water and 20 % of the total energy used in the region. Water, once considered abundant, has become increasingly scarce with declining per capita water availability in Pakistan, India (Gupta and Deshpande 2004), and China (Liu et al. 2007). With about 60 % of the population in India and 65 % in Pakistan relying on groundwater for irrigation (Qureshi et al. 2010), they are already extracting groundwater 56 % and 25 % faster than it can be replenished, respectively. The increased extraction of groundwater has increased demand for energy and lowered the groundwater table in many parts of the HKH region, especially the northwestern Himalayas. This has created a serious concern for the entire region, as the shortage of water and energy severely constrains not only agriculture but also the overall economic growth and human well-being. For example, the energy shortage in Pakistan is causing a loss of about USD 1 billion and 400,000 jobs per annum (GoP 2013). The situation is similar in Bangladesh, India, and Nepal and is challenging overall macroeconomic stability.

Despite the complex interdependency of food, water, and energy among competing uses, each country in the HKH region has put forward a NAPA to address the issues/impacts of climate change using a sectoral adaptation approach, with little or no attention being paid to a nexus-based system-wise adaptation approach to deal with the vulnerability to climatic and non-climate changes. Considering that water, energy, and food are the vital resources for poverty and vulnerability reduction, it is critically important to prioritize and devise an integrated adaptation option based on a nexus assessment that reduces vulnerability to both climate and non-climate changes.

The key features and challenges of food, water, and energy security and their interlinkages are summarized in Table 3.

Synergies in the Water, Energy, and Food Nexus and Adaptation Strategies

Sustainable adaptation options reduce vulnerability to both climate and non-climate changes and address poverty-vulnerability linkage. As water, energy, and food are vital resources for poverty and vulnerability reduction, understanding the linkages among them is critical for adaptation planning. This section attempts to explore potential areas of trade-offs and synergies or complementarities in the water, energy, and food nexus as a new tool to support development of integrated adaptation strategies. Given the complex interplay of water, energy, and food demand and supply, numerous challenges and opportunities exist to minimize trade-offs and promote synergies to formulate sustainable adaptation options.

While some adaptation measures such as water use efficiency, renewable energy, and growing biofuels on wasteland might have positive implications for water, energy, and food resources, other measures for adaptation and mitigation such as

Table 3 Key features and challenges of food, water, and energy security in South Asia

Key characteristics	Adaptation challenges	Food, water, and energy resources and adaptation to climate change
Food security		
Huge chronically undernourished population About half of the world's poor (46 %) and 35 % of the world's undernourished live in South Asia	Provision of food, water, and energy to a large malnourished population without degrading the natural resource base and environment	To meet the nutritional needs of all, food production needs to double in the next 25 years
Burgeoning human population About 25 % of the world's population (projected to reach 2.3 billion by 2050) live in just 3 % of the world's land area	To feed the growing population, agricultural production will have to increase by 70 %, energy by 40 %, and water by 57 %	Increased pressure on land, water, and energy to meet the increased demand
Declining cropland Per capita arable land continually declining due to population growth, urbanization, and increasing biofuel cultivation to meet the energy demand	Limited options for growing more food grain by expanding crop area	Competing demand for land for food, bioenergy production, and ecosystem services
Intensive food production Food production becoming increasingly water and energy intensive	Adapting to the declining groundwater table	Agricultural growth is constrained due to shortage of energy and water
Changing food preferences toward meat The meat production process requires more energy and water	About 7 kg of grain equivalent energy is required to produce 1 kg of meat	Increased pressure on water to meet the food requirement
Sensitivity to climate change Food production is highly vulnerable to climate change due to rising temperatures, accelerated glacial melting, increased evapotranspiration, and erratic rainfall	Uncertainty in water availability due to rapid glacier melt and changes in monsoon pattern in the Himalayas	Climate change is likely to be a critical factor in increasing water and energy demand for food production and land demand for biofuel production
Water security		
Growing water stress Growing water demand for agriculture, energy, industry, and human and livestock use; annual water demand is predicted to increase by 55 % by 2030 compared to 2005	Providing access to safe drinking water in the face of an increasing variability in the water supply	Water-intensive adaptation practices leading to increased water pollution and waterborne diseases, high child mortality, and poor human health

(*continued*)

Table 3 (continued)

Key characteristics	Adaptation challenges	Food, water, and energy resources and adaptation to climate change
Upstream-downstream dependence on water High dependence of downstream communities on the upstream for water to grow food and generate hydropower	Need for enhanced upstream-downstream coordination and cooperation for sustainable development of HKH water resources	Rivers originating in the mountains are a lifeline for dry-season water for irrigation, hydropower, and major economic activities
Increased dependence on groundwater for food production About 70–80 % of agricultural production depends on groundwater irrigation	Adapting to declining water tables	Groundwater pumping for irrigation requires excessive energy which further increases electricity demand
Energy security		
High energy poverty About 63 % of the population without access to electricity; 65 % use biomass for cooking	Providing adequate and reliable energy to a large population without increasing pollution	Growing demand for water and land for energy production
Underutilized potential for hydropower and clean energy	Adaptation options are restricted	Energy diversification to meet the growing demands of food, water, and economic growth

extensive groundwater pumping, desalination plants, and interbasin transfers of water to deal with water scarcity, and growing biofuels to deal with fuel scarcity, may increase nexus challenges (Bazilian et al. 2011). Clearly, any policy designed to reduce vulnerability to climate impacts in one sector will affect and be affected by water, energy, and food linkages.

Promises of a Nexus-Oriented Approach for Sustainable Adaptation: Potential for Synergy

Some sector-specific adaptation measures have the potential to provide synergistic "win-win" opportunities to enhance climate mitigation or adaptation objectives across one or more of the other sectors in the nexus, while other measures may have negative impacts on mitigation or adaptation potential in other sectors (Table 4). For example, increasing the efficiency of freshwater use as an adaptation measure has the potential for synergy across sectors, as it increases the availability of water for energy and agriculture, while reducing emissions per capita. But at the same time, it has potentially negative implications because resiliency gains from water use reductions may be lost if conserved water is used to expand planted

Table 4 Synergies between climate change adaptation and nexus approaches

Sector-specific adaptation measures		Positive implications for the sector	Potential for synergies across the nexus
Water	Increasing water use efficiency	Reduces water use per capita	Increased availability of water for energy and agriculture
	Switching from use of freshwater to wastewater	Reduces freshwater use per capita	Increased availability of freshwater for food, energy, and other uses
	Switching from wet to dry cooling at thermoelectric power plants	Reduces water use and associated thermal pollution	Increased availability of water for energy and agriculture
	Desalinization	Increase in brackish and freshwater supplies	Increased availability of freshwater and overall water supply for energy, agriculture, and other uses
	New storage and conveyance of water to serve new demands	Increased water supplies to meet demand	Increased availability of freshwater and overall water supply for energy, agriculture, and other uses
	Watershed management	Increased water supplies to meet demand	Increased water supply for energy and other uses, improved water quality, reduction in flood potential
Land	Switching to drought-tolerant crops	Increased/ maintained crop yield in drought areas	Reduced water demand
	Using waste or marginal land for biofuels	Increase in renewable energy	Reduced pressure on nonrenewable energy as some fossil fuels are replaced with biofuels
Energy	Increasing transmission capacity	Reduced economic and social impacts	Potential for reduced emissions if new transmission and wind/solar power supplied to the grid
	Increasing renewable energy e.g., solar, wind, biogas	Increased clean energy and reduced pressure on energy	Reduced greenhouse gas emissions, reduced water demand for cooling, thermal power

Adapted from Skaggs et al. (2012)

acreage. Similarly, mere provision of irrigation water does not guarantee productivity because salinization induced by irrigation reduces productivity. Electricity production in China and India also has water use and carbon emission impacts, 78 % and 52 % of total electricity in China and India respectively is generated using fossil fuel (coal). Electricity generation from wind or photovoltaics is typically much less water intensive than generation from fossil fuels. Water smart technologies can save both water and energy while improving food security. For example, micro-irrigation technologies, such as drip and sprinkler irrigation methods, have been proven to be highly efficient in increasing crop productivity while using less water, thereby saving both water and electricity, which is widely use for pumping groundwater (Narayanamoorthy 2007). Experience has shown how increasing water use efficiency could be a win-win option for nexus-based adaptation (UNESCO 2009). In planning and policy, full consideration of such cross-sectoral interactions is critical to devising adaptation options for enhancing synergies and reducing risks.

There are also strong links between energy, food security, and adaptation. Universal access to adequate, affordable, and reliable renewable energy is both an adaptation and a mitigation response to climate change and also enhances other options and choices for adaptation. Growing biofuels on wasteland can enhance the energy supply and thus reduce dependence on fossil fuels. However, diverting cultivable land for biofuels can threaten food security. Holistic adaptation to climate change can also support achieving nexus security by reducing vulnerability and minimizing the risk of disasters. Understanding the potential synergies in the water, energy, food, and adaptation nexus is critical for effective adaptation and sustainable development.

Nexus-based adaptation offers a pathway to a nexus-smart green economy. For such a transition, efforts to attain food security need to be water, land, and energy smart; efforts to achieve energy and climate protection goals need to be water and land smart; and efforts to reach water goals need to be energy and climate smart. As an example, the so-called Jyotigram scheme for improved access to energy for both households and irrigation (water pumping) in Gujarat, India, is a promising integrated approach which has significantly reduced groundwater overexploitation and increased energy and food security, while raising Gujarat's GDP growth above that of the rest of India (Shah et al. 2009). Another example of a nexus-smart green economy is the Mongolia capital, Ulan Bator, the world's second most polluted city, where a 50-MW wind farm was built that will save 18,000 tons of carbon dioxide and 1.6 million tons of water each year. It has led to an abundant potential for a green environment that can help poverty eradication and provide jobs and sustainable development (Slezak 2013).

There are a number of ongoing approaches that can contribute to development of a nexus-smart green economy that supports adaptation. For example, REDD+ intervention (reducing emissions from deforestation and forest degradation) is a promising adaptation measure to conserve or enhance biodiversity and forest ecosystem services (Danielsen et al. 2011). REDD+ contributes to mitigation, by increasing carbon sequestration, and can also be used as an entry point to support more efficient fuel use. At the same time, measures to improve water use and energy efficiency can also support the sustainability of REDD+ interventions and ensure the permanence of carbon stocks by preventing activity displacement and induced deforestation and by limiting or avoiding damage to the ecosystem from extreme weather events. Similarly, payment for ecosystem service (PES) approaches have a potential to contribute to adaptation by enhancing the provision of ecosystem services, enhancing adaptive capacity, and providing incentive mechanisms to encourage communities to adopt specific measures for adaptation to climate change (van de Sand 2012). Costa Rica's PES program demonstrates ways to conserve and regenerate ecosystems and thus improve long-term adaptive capacity (Sánchez-Azofeifa et al. 2007).

Toward a Nexus-Based Framework for Sustainable Adaptation

South Asia faces a difficult challenge in meeting the growing demands of the burgeoning population for food, water, and energy, and the problem of ensuring food, water, and energy security is further compounded by climate change. The goal of adaptation to climate change is to reduce vulnerabilities to both climatic and non-climate changes; thus, it is closely linked with the sustainable use and management of water, energy, and food, which are also vital for sustainable development.

Understanding the role of the water, energy, and food nexus in adaptation is key to designing effective adaptation policies and strategies. The nexus approach is a system-wise approach that recognizes the inherent interdependencies of the food, water, and energy sectors for resource use and seeks to optimize the trade-offs and synergies, thus enabling adaptation responses to be made more effective and sustainable. The nexus outlook can also help to stimulate critical thinking on aligning the sustainable development goals (SDGs) with planetary boundaries in the post-2015 development agenda.

The nexus perspective is critical to finding a common solution for all three sectors, by determining and resolving trade-offs and exploiting potentials for synergy to meet the increasing demand without compromising sustainability. Strategies to facilitate adaptation to climate change need to incorporate the dynamics among water, energy, and food and develop mechanisms for progressive and transformational change that moves from sectoral to trans-sectoral adaptation. The complex interplay of food, energy, and water demand and supply requires a holistic approach to address the twin challenges of poverty and vulnerability for sustainable adaptation. A framework is required in order to move from a sectoral to a holistic approach. Development of a detailed framework is beyond the scope of this paper; however, a broad approach is outlined, which can be seen as explorative.

Figure 1 suggests an outline for a broad framework for a nexus-based approach to sustainable adaptation. This outline is intended to stimulate critical thinking rather than provide definitive answers. First and foremost is the need to take a nexus-based adaptation perspective in determining the trade-offs and synergies associated with the complex interplay of food, energy, and water demand and supply. The Area A in the Venn diagram represents the situation of an integrated nexus-based response strategy for sustainable adaptation to ensure the security of all three sectors. The second component represents the core policy action fields and associated outcomes that underpin the three sustainability dimensions: economic (increasing resource efficiency), social (accelerating access for all), and environmental (investing to sustain ecosystem services). Finally the third component stresses the need to target the poverty-vulnerability linkages (overlap between poverty eradication and vulnerability reduction) to reduce poverty and vulnerability concurrently, rather than treating them separately, in order to ensure that adaptation solutions are sustainable.

The framework illustrates the need to understand how the context of vulnerability to both climate and non-climate change influences the development of poverty and how people adjust their adaptation strategies, before devising a

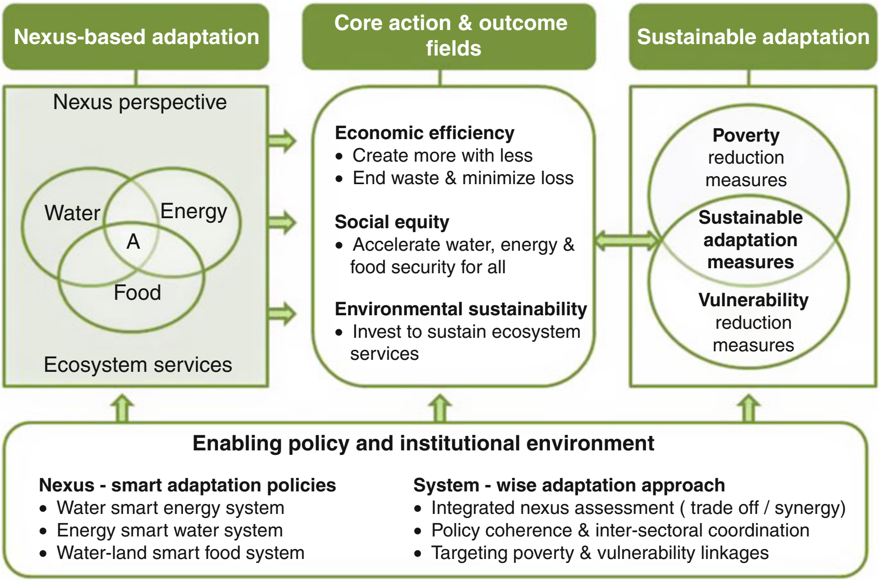

Fig. 1 Outline for a nexus-based adaptation framework to ensure sustainable solutions

nexus-based response strategy. It also shows why adaptation should be an integral part of sustainable development, with climate change implications factored into all development planning, decision-making, and implementation (Leal 2011). In this sense, the framework underscores the importance of identifying the potential synergies and trade-offs between adaptation and mitigation measures and of integrating them in a two-pronged approach to managing the short- and long-term disturbances to the climate in the pursuit of sustainable development. The following are some broad recommendations:

- **Tap new water and energy sources to alleviate competition across sectors:** New sources of water and energy should be exploited through investment in renewable energy, rain and storm water harvesting, widely distributed water storage activities, and reuse of water to alleviate competition across sectors for water and energy.
- **Deepen the nexus knowledge base:** Develop analytical frameworks to better understand challenges and find opportunities for potential synergies in the water, energy, and food nexus and sustainable adaptation. There is a dearth of knowledge about interconnections between water, food, and energy in terms of resource use intensity and the possible areas of trade-offs and synergies, including benefit and cost dynamics and their distributive implications.
- **Promote a system-wise adaptation approach for win-win solutions:** Move from a sectoral to a trans-sectoral approach so that different adaptation responses and measures support each other, synergy is enhanced, and trade-offs are minimized and efficiencies are enhanced.

- **Strengthen policy integration and policy coherence**: Strengthen policy integration and policy coherence, while strengthening institutional capacity for coordinating/managing the water, energy, and food nexus and adaptation together in a holistic way, through stronger integration and governance mechanisms across sectors and among the major actors (public-private-civil society partnerships).
- **Protect essential natural and environmental resources:** Protect essential natural and environmental resources and design mechanisms to include externalities into decision-making by introducing appropriate incentives and regulations.
- **Place nexus-smart policy for adaptation at the center of national development strategies**: Operationalizing the nexus perspective as a tool for adaptation requires appropriate policies and institutional capacities to manage coordination across sectors.

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Part III

Climate Change Adaptation, Agriculture, and Water Security

Adaptation According to Mode of Climate Variability: A Case Study from Canada's Western Interior

David Sauchyn, Barrie Bonsal, Stefan W. Kienzle, Jeannine-Marie St. Jacques, Jessica Vanstone, and Elaine Wheaton

Contents

Abstract

Successful economies, and sustainable communities, are adapted to the historical mean state of the climate of the region and, to a large extent, to the historical interannual and seasonal variability, with which there is much experience. This adaptation involves familiar strategies, for example, irrigation, and the

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corresponding policies, programs, and best practices. There is less experience, however, and therefore fewer adaptation options, in dealing with decadal to multi-decadal modes of climate variability and with unprecedented climate extremes. This scale of variability and extreme events requires a different suite of adaptations that generally are not supported by existing policy and programming. This asymmetry in historical and planned adaptation is illustrated with a case study from Canada's western interior, which has a climate characterized by differences in temperature and precipitation between seasons and years that are among the largest on earth. This chapter examines the interannual to multi-decadal variability of the past millennium, extremes of the past 100 years, and projections of climate change. Municipalities and industry must recognize these multiple modes of variability as they pursue adaptation planning to minimize the impacts of climate change, including unprecedented drought and excess moisture.

Keywords
Western Canada • Climate change and variability • Asymmetric adaptation

Introduction

Communities and economies are vulnerable to the adverse effects of climate change. This vulnerability is a function of (1) exposure to climate hazards and their impacts and (2) social conditions that determine (a) sensitivity, the degree to which a system is affected by climate-related stimuli, and (b) adaptive capacity, the ability of a system to adjust to climate risks and opportunities by increasing its resilience or coping range (Smit and Johanna 2006). Adaptive capacity depends on access to financial, social, and natural resources and institutions, the management of current and past stresses, and the ability of institutions and individuals to learn from experience and to anticipate and plan for future change (Armitage 2005). When exposed to the impacts of climate change, the adaptive response will depend largely on the capacity of a community to deal with the impacts and risks. Thus, vulnerability is determined mostly by social factors, and exposure to climate change is often treated as given in the assessment of social vulnerability. These determinants of vulnerability to climate change are illustrated in Fig. 1. According to this common conceptual framework, the assessment of vulnerability to future climate conditions begins with an understanding of sensitivity and adaptation to past and current climate events and variability.

The box labeled "Future Climate Conditions" in Fig. 1 is a climate change scenario, "a plausible future climate that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change" (IPCC-TGCIA 2007). Climate change scenarios can be simple arbitrary adjustments to climate variables, or they can consist of climate data derived from other locations or times in the past (analogues), where/when the climate is/was similar to the future conditions anticipated at the current location. However, the most robust and precise

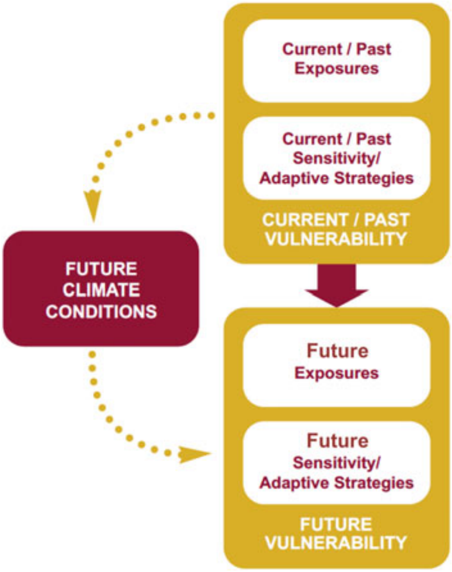

Fig. 1 The standard conceptual framework or vulnerability assessment model (After: Smit and Johanna, 2006)

climate scenarios are derived from global climate models (GCM), "the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations" (IPCC 2007). The conventional approach to deriving climate change scenarios from GCMs, recommended by the IPCC Task Group on Scenarios for Climate Impact Assessment (IPCC-TGCIA 1999, 2007), is illustrated in Fig. 2 using a time series of modeled mean annual temperatures from the Canadian Prairies. According to this standard method, a climate change scenario is the difference in average climate between past and future 30-year periods. This approach reflects a historical lack of confidence in the reliability of short-term (annual to decadal) climate projections. A 30-year mean is the equivalent of a climate normal; it masks the short-term variability and represents the most reliable output from climate models.

GCM projections are less reliable over shorter time frames and smaller spatial domains and for precipitation and other variables related to atmospheric circulation and dynamics. Regional aspects of climate change are controlled by atmospheric circulation patterns, such as the location of the jet stream, but unfortunately the model simulation of the dynamical response of the climate system to anthropogenic forcing is highly uncertain. Climate models simulate the thermodynamics of the climate system and thus temperature, snowmelt, sea ice extent, sea level rise, etc., with greater confidence and consistency. In many regions, however, the most challenging impacts of climate change are not trends in temperature-related variables but rather shifts in the distribution of water supplies and changes in the frequency and severity of extreme weather events (e.g., flooding and drought).

Researchers and practitioners have long recognized the more immediate and challenging impacts are climate extremes and variability, departures from mean

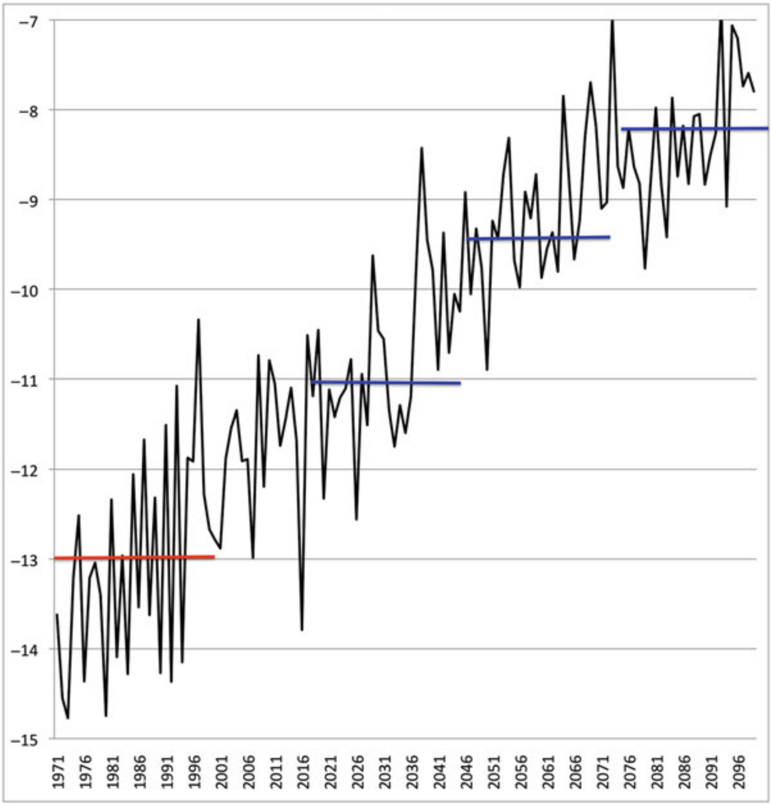

Fig. 2 Mean winter surface air temperature (° C) for the Canadian Prairies from the model CGCM3 (T47) using the SRES A1B greenhouse gas emission scenario. A climate change scenario is the difference (or ratio in the case of precipitation) between the mean value for the baseline period 1971–2000 (*red line*) and the 30-year mean values (*blue lines*) for 2010–2039 (the 2020s), 2040–2069 (the 2050s), and 2070–2099 (the 2080s)

conditions, whether natural (internal) variability or the consequences of global warming. This was clearly pointed out in the 1990s in papers such as "Extreme events in a changing climate: Variability is more important than averages" by Katz and Brown (1992) and "Relative impacts of human-induced climate change and natural climate variability" by Hulme et al. (1999). Much more recently, Deser et al. (2012) pointed out that future climate will be dominated by natural variability for the foreseeable future, and this limits the capacity of climate models to provide predictions of the response of climate regimes to anthropogenic forcing. They demonstrated for North America that natural climate variability "poses inherent limits to climate predictability and the related goal of adaptation guidance" although "other locations with low natural variability show a more predictable future in which anthropogenic forcing can be more readily identified."

Figure 3 is another, more detailed, illustration of the use of climate and social scenarios for impact and adaption assessment and specifically for informing the formulation of policy. The distinction between "top-down" and "bottom-up" approaches has implications for relative roles of researchers from different disciplines and the stage at which local information is introduced. The top-down approach begins with scenarios of global climate and environmental response to anthropogenic forcing and global trends in socioeconomic variables that dictate emissions of greenhouse gases. These global scenarios are then downscaled and applied to the assessment of regional impacts and adaptation options. This approach is typical of multinational climate change assessment that informs international policy, notably the Intergovernmental Panel on Climate Change (IPCC) and the Kyoto Protocol, respectively. Typically, as shown in Fig. 3, stakeholders are engaged to frame regional or national socioeconomic scenarios and adaptation strategies. The strength, and weakness, of the top-down approach is that it relies on the expertise of natural and social scientists to frame the problems and thus chose the appropriate variables and sources of data.

As climate change scientists, the authors of this chapter are familiar and comfortable with a top-down approach, where information about past and future climate variations is generated and delivered largely outside the context of specific vulnerabilities of local communities. The climate change scenarios are projections of trends in those climate variables that are most readily analyzed with the most confidence and precision and that the scientists consider most relevant in terms of the regional climate regime. We have also been engaged, however, in multidisciplinary impacts and adaptation research projects that have taken a "bottom-up" approach to integrating climate science, structural institutional conditions and agency, and the perspectives of stakeholders and decision makers. For example, Diaz et al. (2009) applied the vulnerability framework in Fig. 1 to a multicollaborative study of institutional adaptation to climate change in northern Chile and western Canada. This work highlighted the central role of public institutions in developing adaptive capacity to climate change, but it also demonstrated significant gaps in knowledge and governance practices that lead to a deficit in adaptive capacity.

The bottom-up approach is well suited to the local and regional scales at which the impacts occur and adaptations are identified and implemented. The initial step in Fig. 3 of collecting baseline climate and environmental and socioeconomic data produces a profile of communities that include problems (vulnerabilities) and variables informed by knowledge of local conditions. The bottom-up approach thus combines the observation of local climate change and impacts, and adaptive capacity, with data on projected impacts derived from downscaled outputs from climate and environmental models and adaptation/socioeconomic scenarios. From the perspective of climate science, there is one major implication of the bottom-up approach. Because the relevance of climate variables depends on local conditions, including the perspectives and observations of local people, the most relevant climate risks and variables often are not those that can be analyzed and modeled with confidence and precision. The most serious and relevant climate risks often are understood with the least certainty.

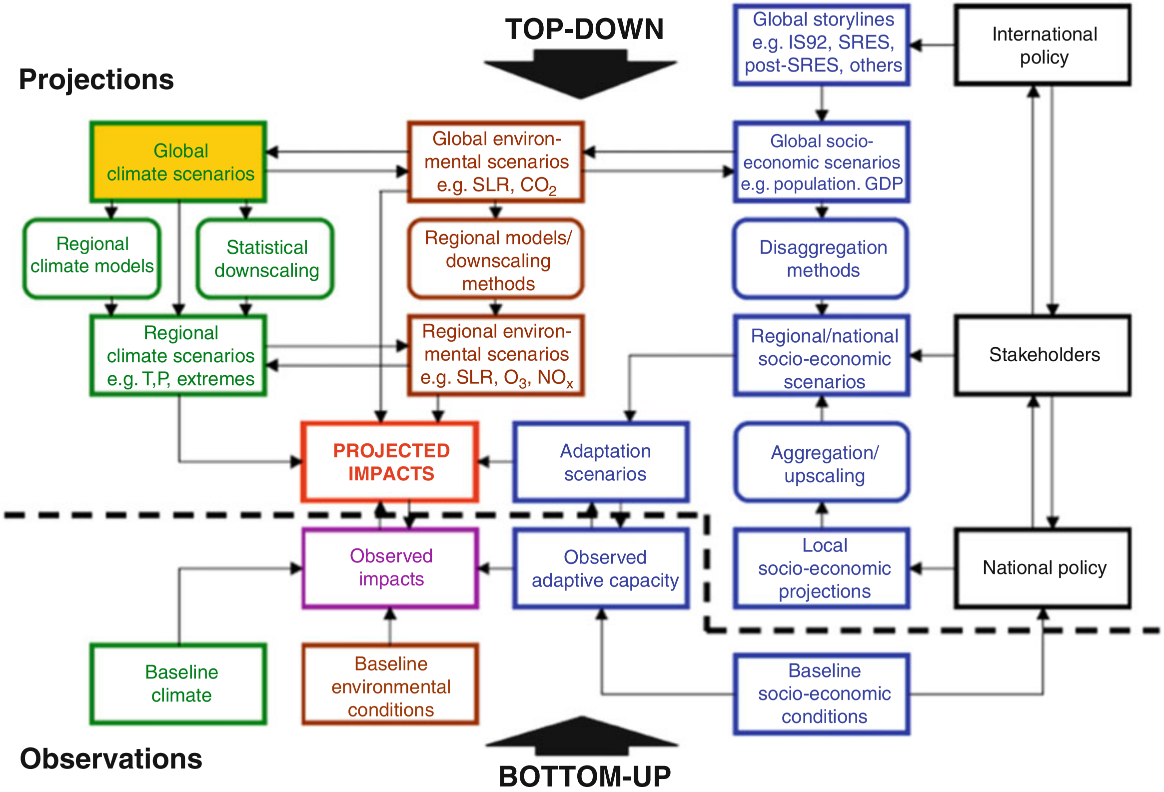

Fig. 3 The *top-down* and *bottom-up* approaches to informing climate change policy with climate and socioeconomic scenarios and related source of data. Information above the dashed is projections and output from models; below the line are observations and the results of data collection in the field (Source: IPCC-TGCIA (2007))

This brief overview of the use of climate change scenarios for the assessment of climate change vulnerability, impacts, and adaptation is an important context for this chapter that explores the disparity between these standard practices in research and application and our experience with the study and scientific support of planned adaptation to climate fluctuations over a range of frequencies or modes of variability. This chapter examines the adaptation strategies adopted by rural agricultural communities in the context of the climate variability of the past millennium, climate extremes of the past 100 years, and anticipated shifts in variability and extremes in a warming climate. We discuss the extent to which rural agricultural communities recognize multiple modes of climate variability and are engaged in adaptation planning to minimize the impacts of drought and excess moisture.

The Case Study: The Canadian Prairies

This chapter argues that the best adaptive adjustments to practices and policies are conditional on the mode of variability to which a community is exposed. Canada's western interior makes an ideal case study to present and demonstrate this argument. It is exposed to an extremely variable climate and some significant projected climate change impacts. Furthermore, the resource-based economy is sensitive to the impacts of climate change on ecological goods and services and particularly water. Among the regional resource industries, this chapter is focused on agriculture. More than 80 % of Canada's agricultural land is in the Prairie Provinces of Alberta, Saskatchewan, and Manitoba. The agriculture sector has an adaptive capacity that has been described as high, which is attributable in large part to a history of adaptation to climate risks.

While the frost-free growing season is relatively short and precipitation is low, ranging on average from 300 to 500 mm per year, the greater challenge for commercial agriculture is the climate variability from year to year. A good indication of the degree of this climate variability is the interannual variation (coefficient of variation) in the climate moisture index (CMI), a measure of the ratio of precipitation to atmospheric water demand (evapotranspiration). An analysis of a global dataset by the Water Systems Analysis Group at University of New Hampshire (wwdrii.sr.unh.edu) showed that the highest year-to-year fluctuations in CMI occur along the humid and dry transition between forest and grassland ecosystems. These areas are characterized by periodic, severe droughts and thus are vulnerable to water stress and/or scarcity. The most extensive regions of extremely variable hydroclimate are in north-central Asia and the northern Great Plains of North American and specifically the Canadian Prairies.

Despite these almost marginal climate conditions for commercial agriculture, a viable export industry has developed over the past 100 years. Annual crop yields in the Canadian Prairies are medium to high, relative to the global range (Foley et al. 2011), despite the northerly latitudes and dry and variable climate. This level of crop productivity extends to a latitude of almost 60°N in northern Alberta. The Canadian Prairies are anomalous; in no place else does commercial agriculture

Fig. 4 The landscape of southwestern Alberta in the vicinity of the village of Enchant. This entire landscape is an expression of adaptation to a dry climate. Center pivot irrigation is the dominant feature. An irrigation canal transects the image from the *upper left corner* to the *middle* of the *right edge*. Rain-fed "dryland" crop production is practiced in strips mostly perpendicular to the prevailing winds to prevent wind erosion and preserve moisture (melting snow) (Source: Google Earth)

succeed at a large scale in a continental climate at high latitudes. This agricultural productivity reflects adaptation to make most efficient use of these marginal climate resources. Adaptation of agricultural practices, policies, and structures to a dry cold continental climate is embedded in the history and landscape of the Canadian Prairies. A complete transformation of the native prairie ecosystems was achieved with the adaptation of farming practices imported originally from the more humid climates of Europe and eastern Canada. Figure 4 is satellite image of southwestern Alberta in the vicinity of the village of Enchant. The structures and land use patterns, mostly related to irrigation, reflect the use and management of water. Beyond the area in this image and throughout the Prairie Ecozone, thousands of reservoirs and "dugouts" and thousands of kilometers of shelterbelts (rows of trees and shrubs) are other adaptations to conserve water and soil.

The Euro-Canadian history of the Canadian Prairies is punctuated by the impacts of drought and the adaptations in response. Sensitivity to drought varies according to type, reliability, and accessibility to water supplies and their management. Snow and glacier melt in the Rocky Mountains is the source of water for irrigation in southern Alberta and parts of Saskatchewan and the water supply for most of the population in these two provinces. In terms of land area, however, most prairie agriculture is dryland farming dependent on precipitation and local runoff. These climatic and hydrographic circumstances dictate the exposure of rural communities and economies to climate risk and the relevance of hydroclimatic factors and variables for an assessment of impacts and adaptation. Because climate fluctuates at various scales from seasonal to decadal to longer-term trends, adaptation to mitigate the impacts of climate variability and change requires an understanding of the risks posed by different modes of climate variability in terms of their likelihood and consequences. These scales or modes of variability are not arbitrary or statistically convenient intervals; there are distinct periodicities corresponding to certain external and internal causes of climate variability. At high frequencies, climate varies between seasons and years. Lower-frequency variability is not as well defined, or understood, but there are dominant modes at decadal and multi-decadal scales. Interannual to multi-decadal cycles have been linked to internal behavior of the climate system and specifically to organized interaction between the oceans and atmosphere (e.g., El Niño Southern Oscillation, ENSO, and the Pacific Decadal Oscillation, PDO) and associated teleconnections to regional climate regimes (Bonsal et al. 2001; Lapp et al. 2013). Longer-term climate trends are related to slow changes in the external controls on climate (i.e., radiative forcing) and centennial-scale shifts in climate that are detectable only in paleoclimate records. This entire range of climate variability has been observed in our study area, Canada’s western interior.

The Historical Record of Seasonal to Interannual Variability and Trends

Climate Variables

Annual and seasonal means of temperature and precipitation, derived from instrumental weather data, define the “normals” for a regional climate regime. In terms of climate risks, however, the most relevant variables are those that impose constraints and threaten productivity and livelihoods. Table 1 is a list of these most relevant agroclimatic variables and indices of climate extremes for the rural communities and agricultural economy of the Canadian Prairies. In a recent analysis of trends in some of these variables, Qian et al. (2012) found that the growing season has lengthened, frost-free days have increased, cold stress has decreased, and heat units are greater than in earlier decades. For example, growing season length has increased about 16–20 days across the southern prairies from 1911–1940 to 1971–2000. Changes in water deficit in the growing season were not statistically significant, and only a few stations had a significant difference in the variances of agroclimatic variables. They concluded that adaptation should include the use of new crop varieties that can benefit from longer and warmer growing season, while withstanding increased risks of heat damage.

Data for the analysis of the climate indices in Table 1 are available from the National Land and Water Information Services (NLWIS) in the form of a daily 10 km gridded climate dataset (1950–2010) for the Canadian landmass south of 60°N. These data were interpolated from the 7,514 climate stations in the Canadian Climate Data Archives (Hutchinson et al. 2009). We used the rank-based

Table 1 The most relevant climate indices for rural communities and the agricultural economy of the Canadian Prairies

Variable	Description	Units
Tmax >= threshold temperature	Annual count when the daily maximum temperature >= chosen threshold temperature, e.g., 25 °C	Days
Tmax <= threshold temperature	Annual count when the daily maximum temperature <= chosen threshold temperature, e.g., 2 °C	Days
Tmin >= threshold temperature	Annual count when the daily minimum temperature >= chosen threshold temperature, e.g., 5 °C	Days
Tmin <= threshold temperature	Annual count when the daily minimum temperature <= chosen threshold temperature, e.g., 0 °C	Days
Frost days	Annual count when daily minimum temperature < 0 °C	Days
Growing season length	Annual count between first span of at least 6 days with Tmean >5 °C and first span after July of 6 days with Tmean < 5 °C	Days
Heat wave days	Count of days in a year that are 5 °C higher than during the 1961–1990 period	Days
Ice days	Annual count when daily maximum temperature <0 °C	Days
Max Tmax	Monthly maximum value of daily maximum temp	°C
Max Tmin	Monthly maximum value of daily minimum temp	°C
Min Tmax	Monthly minimum value of daily maximum temp	°C
Min Tmin	Monthly minimum value of daily minimum temp	°C
Cool nights	Percentage of days when TN < 10th percentile	%
Cool days	Percentage of days when TX < 10th percentile	%
Warm nights	Percentage of days when TN > 90th percentile	%
Warm days	Percentage of days when TX > 90th percentile	%
Consecutive dry days	Maximum number of consecutive days with RR < 1 mm	Days
Accumulated precipitation over 5 days	Annual maximum sum of 5-day precipitation	Mm
Simple precipitation intensity index	Annual fraction of annual precipitation sum divided by the number of precipitation days > 1 mm	Mm
Very wet years	Annual total precipitation when above the 1961–1990 period 95th percentile	Years
Annual precipitation	Annual sums of daily precipitation	mm
Warm spell duration indicator	Annual count of days with at least six consecutive days when TX > 90th percentile	Days
Cold spell duration indicator	Annual count of days with at least six consecutive days when TN < 10th percentile	Days
Diurnal temperature range	Monthly mean difference between TX and TN	°C
Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as precipitation >= 1.0 mm) in the year	mm/day

(*continued*)

Table 1 (continued)

Variable	Description	Units
Number of heavy precipitation days	Annual count of days when daily precipitation >= 10 mm	Days
Number of very heavy precipitation days	Annual count of days when daily precipitation >= 20 mm	Days
Number of days above nn mm	Annual count of days when daily precipitation >= nn mm, nn is user defined threshold	Days
Consecutive wet days	Maximum number of consecutive days with precipitation >= 1 mm	mm
Very wet days	Annual total PRCP when RR > 95th percentile	mm
Extremely wet days	Annual total PRCP when RR > 99th percentile	mm
Annual total wet-day precipitation	Annual total PRCP in wet days (RR >= 1 mm)	mm
Growing degree days >= 0 °C	Annual sum of daily temperatures >= 0 °C	°C
Growing degree days >= 5 °C	Annual sum of daily temperatures >= 5 °C	°C
Growing degree days >=10 °C	Annual sum of daily temperatures >=10 °C	°C
Beginning day of growing season	First day of span of at least 6 days with Tmean >5 °C	°C
End day of growing season	Last day of span of at least 6 days with Tmean <5 °C	°C

Table 2 Trends of selected climate indices for some selected locations in the Canadian prairies (confidence level in brackets)

Location	Annual frost days (days)	Growing season (days)	Heat wave duration index (days)	Annual precipitation (mm)	Growing degree days over 5 °C (°C)
Pincher Creek	−24 (99 %)	+17 (80 %)	+13 (90 %)	−58 (<80 %)	+126 (90 %)
Lethbridge	−9 (90 %)	+21 (95 %)	+19 (99 %)	−76 (90 %)	+132 (95 %)
Taber	−12 (95 %)	+33 (99 %)	+19 (95 %)	−10 (<80 %)	+183 (99 %)
Swift Current Creek	−17 (99 %)	+9 (<80 %)	+12 (90 %)	+2 (<80 %)	+136 (90 %)

nonparametric Mann–Kendall statistical test to analyze the significance of trends in these hydrometeorological time series. Table 2 lists trends in selected climate indices for some selected locations in the Canadian Prairies.

It is evident from this trend analysis that climate change has already impacted prairie agro-hydrological conditions in terms of fewer frost days, a longer growing season, more heat waves, a decline in precipitation in Alberta, and an increase in growing degree days over 5 °C. Figure 5 shows the interannual variation around a

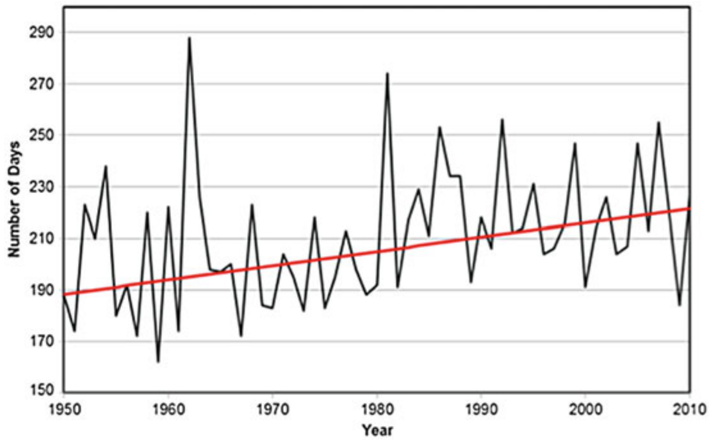

Fig. 5 Time series of the length of the annual growing season and nonparametric trend line for Taber, Alberta. There is considerable interannual variation

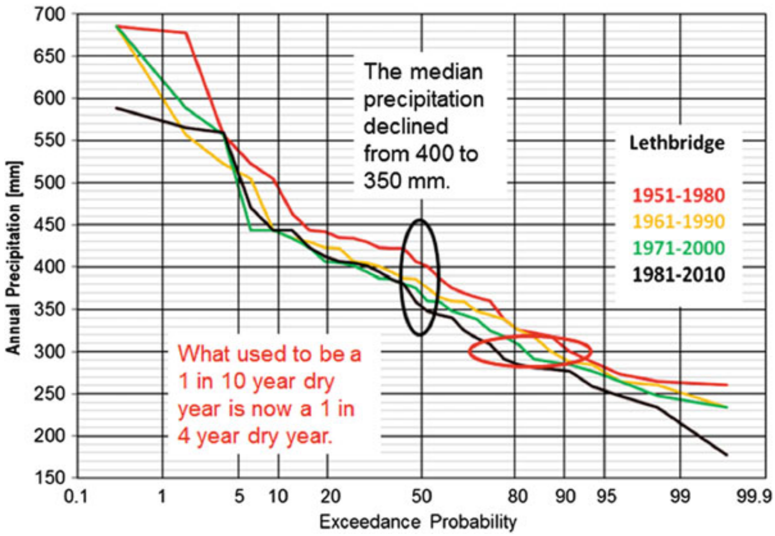

Fig. 6 The exceedence probabilities of four climate normal periods reveal a trend in median annual precipitation at Lethbridge, Alberta. It has declined from 400 mm per year in the period 1951–1980 to a median of 350 mm per year in the period 1981–2010. There is also an increased risk of having a low precipitation year. The probability of 300 mm or less of annual precipitation has increased from once every 10 years in the period 1951–1980 to more than once in 4 years in the 1981–2010 period. This has effects on the sustainability of rain-fed agriculture

trend of increasing growing season length for the town of Taber, Alberta. Figure 6 shows how precipitation normals have changed at Lethbridge, Alberta.

Several indices (usually specific to certain types of drought) have been devised to quantify moisture variability and, subsequently, assess the occurrence of drought

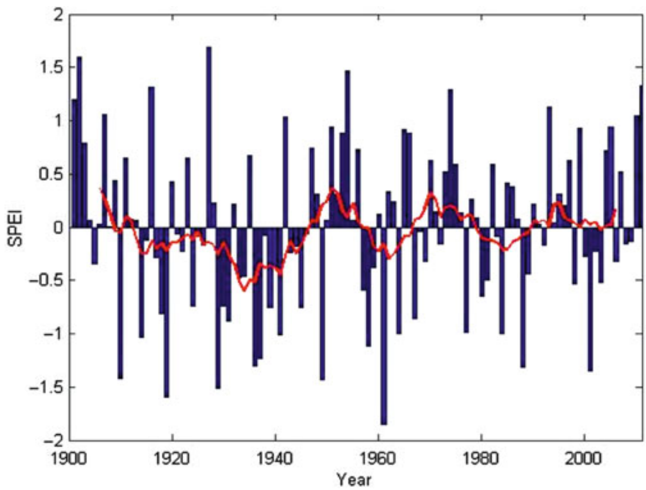

Fig. 7 Areally averaged, agricultural year (September to August) SPEI values over the southern Canadian Prairies (49°N–54°N, 115°W–100°W) for the period 1900–2011. The *red line* denotes the 11-year running mean

and excessive moisture patterns over various regions of the globe including the Canadian Prairies (see Bonsal et al. (2011) for a comprehensive review). A recently developed index, namely, the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010), has been gaining popularity in the literature since it incorporates both precipitation and temperature in its calculation and can be computed for any region of the world at multiple time scales. Figure 7 shows areally averaged, agricultural year (September to August) SPEI values over the southern Canadian Prairie Provinces for the period 1900–2011. Note that negative values represent drier conditions, while positive SPEI correspond to wetter than normal periods. The time series reveals considerable interannual and inter-decadal fluctuations with no discernible long-term trend. Major large-scale droughts occurred during the late 1910s, most of the 1930s and early 1940s, 1958–1961 (with 1961 being the driest year on record), most of the 1980s, and the early 2000s. Conversely, excessive moisture conditions were observed during the early 1900s, much of the 1950s, the 1970s, the late 1990s, and most recently in 2010–2011. Figure 7 reemphasizes the high degree of natural variability in prairie moisture conditions during the instrumental period of record.

Hydrologic Variables

For a region of high natural hydroclimatic variability, such as the Canadian Prairies, it is reasonable to ask if global warming trends can be detected in relatively short instrumental records. Given the economic, environmental, and historical significance of water and the impacts of periodic drought, water levels gauges were

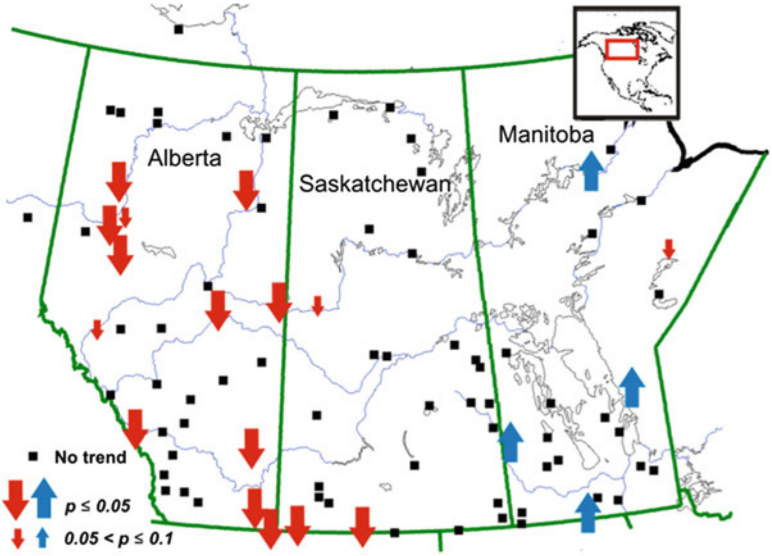

Fig. 8 Geographic pattern of trends in 86 naturally flowing mean-daily streamflow records from the Canadian Prairie Provinces as assessed by a modified Mann–Kendall test. A *red down* (*blue up*) *arrow* denotes a decreasing (increasing) trend; a *black square* denotes no trend

installed at many locations beginning in the early twentieth century. St. Jacques et al. (in press) performed a modified Mann–Kendal trend analysis on 86 naturally flowing streams with active gauges drawn from across the three Prairie Provinces (Fig. 8). The results show a distinct geographic pattern with streamflow generally decreasing in Alberta, some gauges recording increasing flow in Manitoba and few trends in Saskatchewan. The eastern Prairies are responding differently to climate change than the west, with increasing streamflows in Manitoba. These increasing flows have also been detected in neighboring North Dakota.

Further analysis of mean annual streamflow in Alberta for 102 watersheds reveals that 60 time series have negative trends; 14 watersheds had a negative streamflow of over 1 % per year, which means that after 10 years, over 10 % less streamflow would be available if these trends were to continue. The detection of a statistically significant trend does not necessarily imply a trend of practical significance and vice versa. For example, a statistically significant negative trend of 0.1 % per year may be negligible for the water users, while a negative trend of 2 % per year may be of low statistical significance (e.g., 80 % confidence level), given the length of the record and variability around the trend, but have large practical implications within 10 or 20 years. Therefore, the magnitudes of possible streamflow trends need to be reported.

Figure 9 is an example of declining mountain streamflow. The annual hydrograph of the Bow River at Banff, Alberta, has a declining trend (red line). It also exhibits high interannual variability, related to ENSO, and decadal shifts between periods of higher and lower flow, related to the PDO. Runoff from the

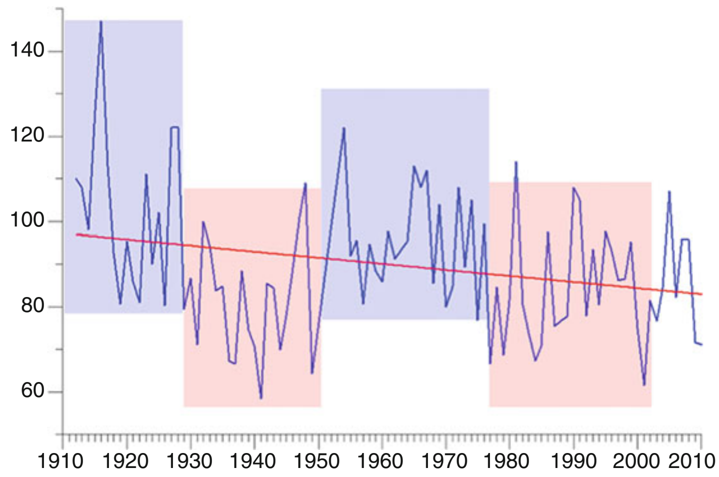

Fig. 9 Mean annual flow (m^3/s) of the Bow River at Banff, Alberta, 1911–2010. The *red line* represents a trend of decreasing annual flow. The *shaded rectangles* represent periods of higher (*blue*) and lower (*red*) flow related to the phase of the PDO

Rocky Mountains is mostly from melting snow. Winter precipitation in western Canada is higher when the PDO is in a negative phase (1890–1924, 1947–1976) and lower when the PDO is in a positive phase (1925–1946, 1977–2008) (Mantua et al. 1997). Streamflow records that span 1½–2 cycles of the PDO, such as the annual time series for the Bow River in Fig. 9, are likely to have declining trends that are the effect of climate change rather than an artifact of multi-decadal periodicity in flow (St. Jacques et al. 2010).

Paleo-Record of Interannual to Multi-decadal Variability

The trends and variability in recorded climate and hydrology documented above (Table 2, Figs. 5, 6, 7, 8, and 9) have important implications for agricultural production and the supply and management of water. This analysis revealed, however, that the detection and interpretation of trends are complicated by the large degree of interannual and decadal variability, including the ~60 year PDO cycle. Paleoclimatic time series provide a longer-term historical context for the interpretation of instrumental data and climate model projections. Tree rings from the subhumid margins of semiarid environments, such as the Canadian Prairies, are especially good proxies of the water budget and measured variables such as precipitation and streamflow (Sauchyn et al., 2011). Using standardized tree-ring width data, the water year (Oct–Sep) flow of the Bow River at Banff was reconstructed from 1107 to 2007 (Fig. 10). The tree-ring data explain about 40–50 % of the variance in the gauge record back to about1650, and then the R^2 declines to about 30 %. Most of the unexplained variance is the underestimation of

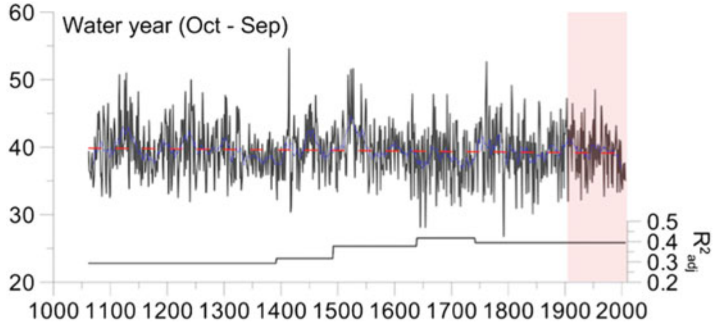

Fig. 10 Water year (Oct–Sep) flow of the Bow River at Banff from 1107–2007 as reconstructed from tree rings. The *pink* portion is the period of instrumental observation used for the calibration of the tree-ring width data. The *dashed red line* is at the level of the mean flow (m^3/sec) for the full reconstruction

high flows, while, on the other hand, tree rings are a good proxy of low flow and drought. The proxy streamflow time series in Fig. 10 indicates that the period of instrumental observation (1911–2007, highlighted with pink shading) is not fully representative of the long-term hydrologic regime. Although 1929–1941, the 1980s and early 2000s stand out as periods of frequent low annual flows, there is a larger range of annual flow prior to the onset of Euro-Canadian settlement and the direct observation of weather and climate. These pre-instrumental low flow periods include the prolonged drought of the mid-nineteenth century when John Palliser declared a large part of the Canadian Prairies "forever comparatively useless" and the extreme low flow of 1796 when to the north at Fort Edmonton furs could not be moved by canoe, "there being no water in the [North Saskatchewan] river" (2003).

The Bow River streamflow reconstruction displays considerable variability around the mean flow depicted with the red dashed line. A spectral (wavelet) analysis reveals that there are two dominant scales of variability in the long-term proxy records of calendar year (Fig. 11a) and water year (Fig. 11b) flow. There is intermittent strong spectral power in the range of 4–12 years, very likely in response to the El Niño Southern Oscillation (ENSO) and also possibly the influence of the 11-year solar cycles of the regional hydroclimate. There also is strong intermittent variability around 60 years, that is, the low frequency of the PDO.

Future Exposure

Ensemble Streamflow Projections

With concern about future flows of the large rivers arising from the Rocky Mountains, there have been various attempts to apply climate model output to projecting future flows. One approach is statistical downscaling: for example,

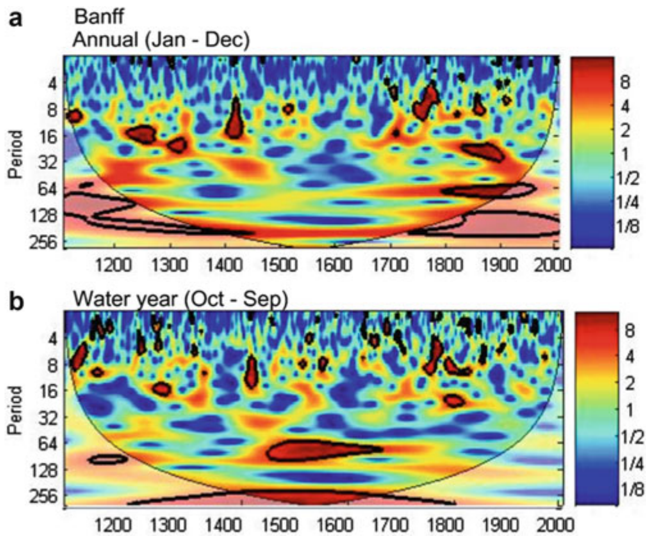

Fig. 11 Wavelet plots derived from the spectral analysis of the Bow River reconstruction: (a) calendar year (Jan–Dec); (b) water year (Oct–Sep). Strong modes of variability are depicted in *red*

streamflow in the South Saskatchewan River Basin can be modeled as a function of the ocean–atmosphere oscillations (St. Jacques et al. 2010) that drive the natural variability of the regional hydroclimatic regime. St. Jacques et al. (2013) drove generalized least squares (GLS) regression models of annual streamflow, using output from an ensemble of 50 runs of ten GCMs from the Phase 3 of the Coupled Model Intercomparison Project (CMIP3) to produce projected streamflows for the twenty-first century. They chose these ten GCMs because they adequately modeled the atmosphere–ocean climate oscillations that affect southern Alberta, i.e., the PDO, ENSO, and Arctic Oscillation. Shown in Fig. 12 are (a) projected flows for the South Saskatchewan River at Medicine Hat and (b) empirical cumulative frequency distributions for three selected years. If business as usual water usage and anthropogenic climate change continue, flows will continue to decline. The curves in Fig. 12b also suggest an increasing probability of extreme low flows.

An alternative approach to projecting future streamflows is the use of physically based hydrologic models with GCM-derived temperature and precipitation as predictors. This method has been applied to the South Saskatchewan River Basin (e.g., Lapp et al. 2009; Shepherd et al. 2010; Larson et al. 2011; MacDonald et al. 2011; Tanzeeba and Gan 2012), and all models projected declining surface water availability for the region. Given that two different methods (statistical versus dynamical) are projecting lower flows in the South Saskatchewan River Basin, there is reason for concern about future surface water supplies in this region where surface water is already over-allocated in some tributaries.

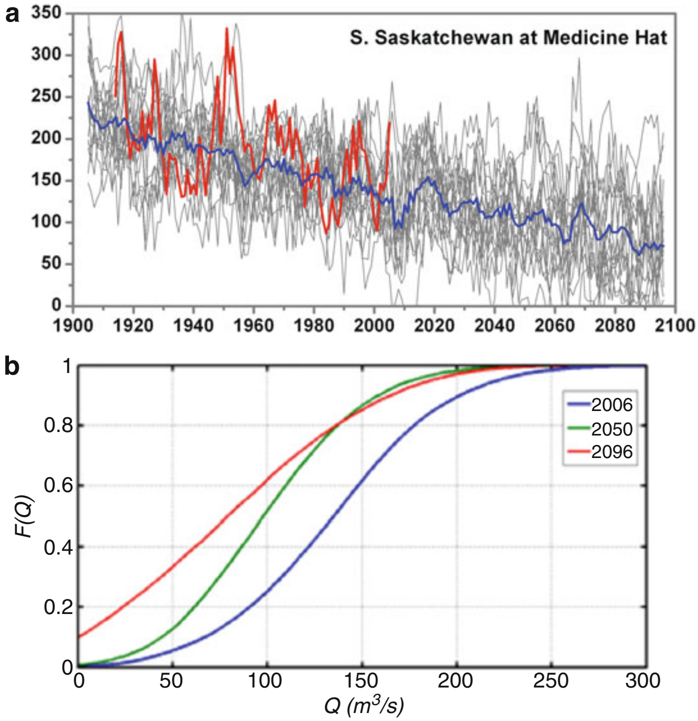

Fig. 12 (**a**) South Saskatchewan River twentieth-century simulations (1900–2005) and twenty-first-century projections (2006–2096 daily mean flows (m^3/s), averaged over the year, smoothed by five-point binomial filters) under the SRES B1, A1B, and A2 emission scenarios. The *red line* is the observed record, the *grey lines* are the individual model runs, and the *blue line* is the all-model mean of the GCM runs. (**b**) Empirical cumulative frequency distributions of projected lightly smoothed (5-year binomial smoother) annual discharges for the South Saskatchewan River

Climate Projections

An assessment of the vulnerability of the Canadian Prairies to climate change is not complete without scenarios of the projected changes in the regional climate as a consequence of anthropogenic global warming. For the purpose of this chapter, climate change scenarios were derived from four global climate models (GCMs) and two higher-resolution regional climate models (RCMs). These models are identified in Table 3. Output from these model runs was obtained from Canadian Climate Change Scenario Network (CCCSN), which is the Canadian repository for climate model output.

The modeling of twenty-first-century climate is based on scenarios of future greenhouse gas (GHG) emissions. For the Fourth IPCC Assessment Report (AR4), the climate model projections were based on the SRES (Special Report on Emission Scenarios) GHG scenarios, labeled B2, A1B, and A2 (Table 3). The “best case” B1 scenario is optimistic and highly unlikely to transpire given recent and historic

Table 3 List of chosen climate models

Model	Country	Resolution	# Twenty-first-century runs			PDO correlation
			B1	**A1B**	**A2**	
CGCM3.1(T63)	Canada	2.8° × 2.8°	1	1	0	0.82
ECHAM5/MPI-OM	Germany	1.875° × 1.865°	2	2	1	0.82
MRI-CGCM2.3.3	Japan	2.8° × 2.8°	5	5	5	0.83
NCAR-PCM	USA	2.8° × 2.8°	2	2	2	0.84
CRCM4.2.3	Canada	0.44° × 0.44°	0	0	1	NA
PRECIS1.8.2	UK	0.44° × 0.44°	0	1	0	NA

GHG emissions and the failure of national governments to achieve a global agreement for the mitigation of climate change. Emission scenario A1B represents the "most likely" future anthropogenic climate forcing; it assumes a mix of technological developments with some use of fossil fuels. SRES A2, the "worst case" or "business as usual" scenario, characterizes a future where socioeconomic trends carry on as at present.

The CCCSN provides output for 65 IPCC-AR4 GCM experiments and for seven runs of RCMs. Reducing this large array of model output to a manageable subset of plausible climate change scenarios, was based on two criteria: (1) projections that span the full range of simulated climate and (2) models that are able to reasonably simulate the ENSO and PDO, since these sea surface temperature oscillations account for much of the interannual to decadal variability in the climate of western Canada. The three scatter plots in Fig. 13 provide a summary of projected changes in mean annual temperature and total annual precipitation, relative to the climate of the baseline period 1971–2000, for the three future time periods 2020s (2011–2040), 2050s (2041–2070), and 2080s (2071–2100). Data from the 65 GCM and seven RCM experiments are plotted. The solid blue lines show the median projected increases in temperature and precipitation. As the twenty-first-century advances, the projected changes increase in magnitude, precipitation by 15–20 % and temperature by 5 °C. The range of values, the departures from the median, also increase reflecting increasing uncertainty in future concentrations of atmospheric greenhouse gases and in the response of the climate system to these higher levels of GHGs.

Figure 13 highlights the 14 chosen experiments: four GCMs by three emission scenarios, plus two RCM runs using single emission scenarios. The output from the selected experiments spans the range of future climates projected by the full set of IPCC-AR4 and RCM model runs.

Whereas this use of scatterplots to display and select output from climate models is common, the second method and criterion applied here is not common but considered necessary given the large degree and impact of internal climate variability in western Canada. Table 3 indicates that for the chosen GCMs, there is a high correlation between modeled and observed characteristics of the ENSO and PDO. These correlations are from Lapp et al. 2011, who evaluated the full set of

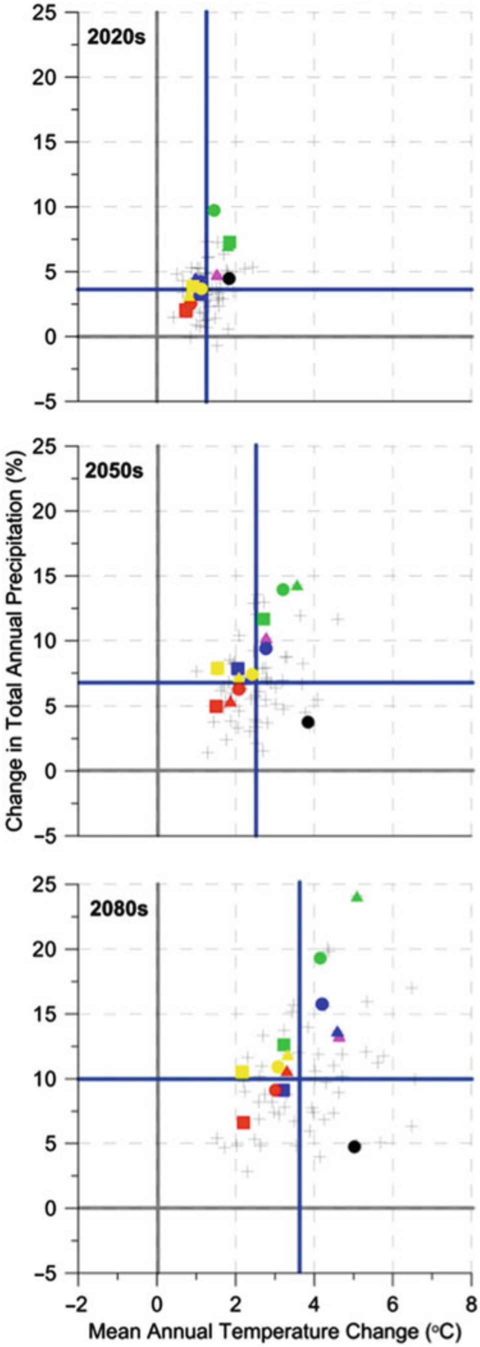

Fig. 13 A scatter plot of change in total annual precipitation (%) versus change in mean annual temperature (°C) from 1971 to 2000 for three future time periods, 2020s, 2050s, and 2080s, as projected by 65 GCMs and seven RCM experiments. The subset of 14 experiments chosen for further analysis is represented with colored symbols: *Green*, CGCM3.1(T63); *Blue*, ECHAM5-OM; *Red*, MRI-CGCM2.3.2a; *Yellow*, NCAR-PCM; *Magenta*, CRCM4.2.3; *Black*, PRECIS1.8.2; SRES GHG emission scenarios: ■ – B1; ● – A1B; ▲ – A2

IPCC-AR4 GCMs in terms of their capacity to simulate the spatial and spectral patterns of the ENSO and PDO. Since the spatial domain of RCMs is limited to a subcontinent and does extend to the oceans, this type of analysis is not applicable.

Whereas the colored symbols in Fig. 13 give the projected changes in annual temperature and precipitation averaged over the Canadian Prairies, the climate model output is available for thousands of point locations on a coarse grid for the GCMs and a much finer grid for the RCMs (the resolutions are given in Table 3). Therefore, the projections for each combination of climate variable, future time period, GCM, RCM, and GHG scenario can be mapped. As an example, Figs. 14 and 15 contain maps of projected total annual precipitation and mean annual temperature for the 2050s, relative to the 1971–2000 baselines, and for the three SRES GHG emission scenarios. While there are discrepancies among models, most of them project reduced precipitation in the western and southern prairies and increased precipitation toward the east and north. The temperature projections are much more consistent with a gradient from smaller to larger increases in temperature from southwest to northeast.

Implications for Adaptation Policies and Practices

Historically prairie agriculture has been sustained through the adjustment of land use and management systems to climatic variability (e.g., drought, early frosts, storms) and to take maximum advantage of soil and water resources. The process of adaptation has occurred episodically in response to periodic water scarcity and to changing markets, technology, and transportation systems. Adjustments have included major changes in farming practices and a significant degree of rural depopulation with the abandonment and consolidation of farms. Given a relatively high adaptive capacity and the historical adaptation that established and sustained commercial agriculture in this dry cold climate, the rural economy and communities could withstand much of the anticipated future change in mean climate.

If the degree of anthropogenic climate change exceeds the historical experience, further adaptation will be required. Adaptation in response to changes in mean temperature and precipitation is a familiar process; prairie agriculture became established by adapting crop and livestock production to a cold climate and low annual precipitation (less than 330 mm over a large area). These adaptations included the development of frost- and drought-tolerant crops or cultivars, adjusting the timing of seeding and harvest and, where water supplies permit, irrigation. Agriculture, and irrigation in particular, accounts for more than 70 % of the consumptive use of surface water (Coote and Gregorich 2000). An expansion of irrigated land is often cited as an effective adaptation to the increased summer aridity anticipated under global warming.

The preceding climate model projections suggest that the future climate of the Canadian Prairies will be warmer and even wetter, but the currently warmest and driest areas will be warmer and drier and currently cooler and wetter areas will be warmer and wetter. The best case scenario for this region, where crop, pasture, and

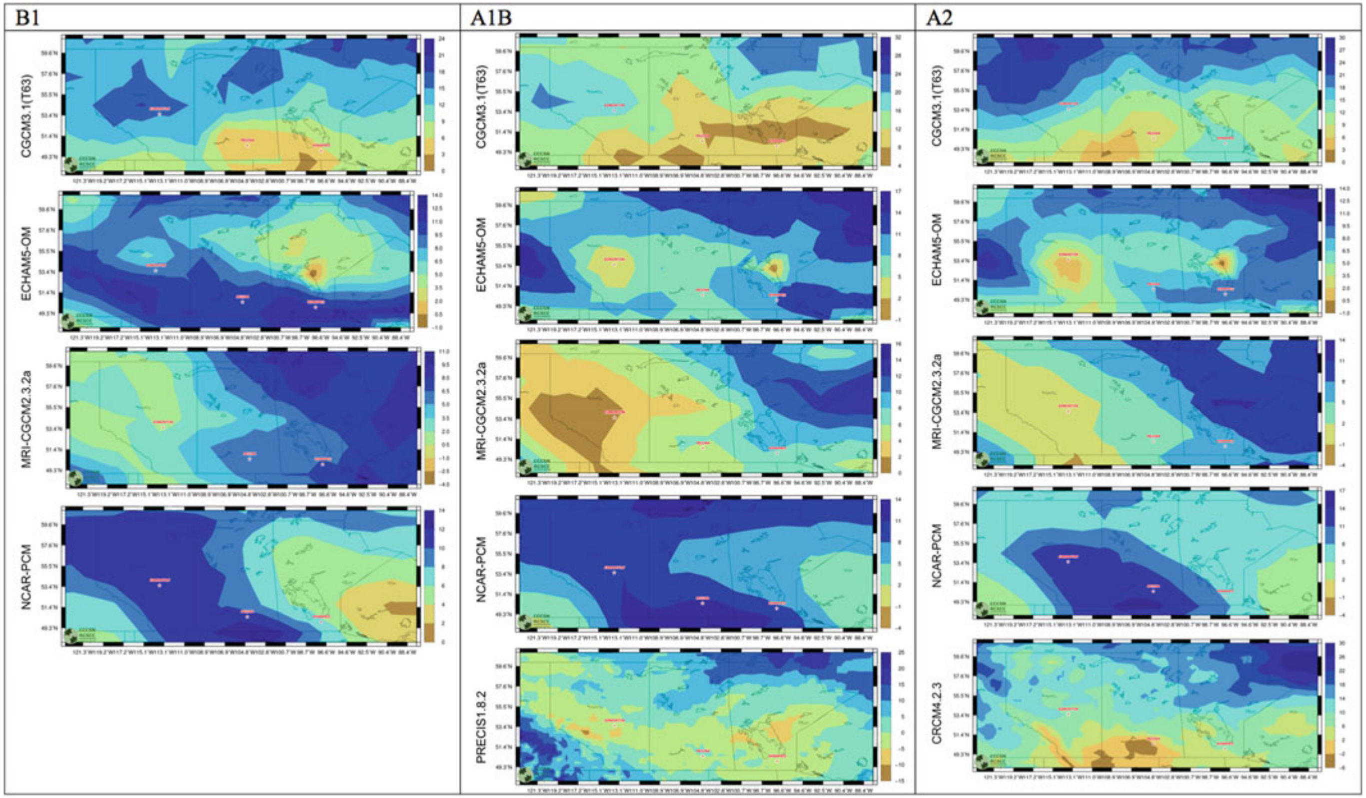

Fig. 14 Projected changes in mean total precipitation for the 2050s (relative to 1971–2000). The climate models and SRES emissions scenarios are identified across the top and along left margin of each map

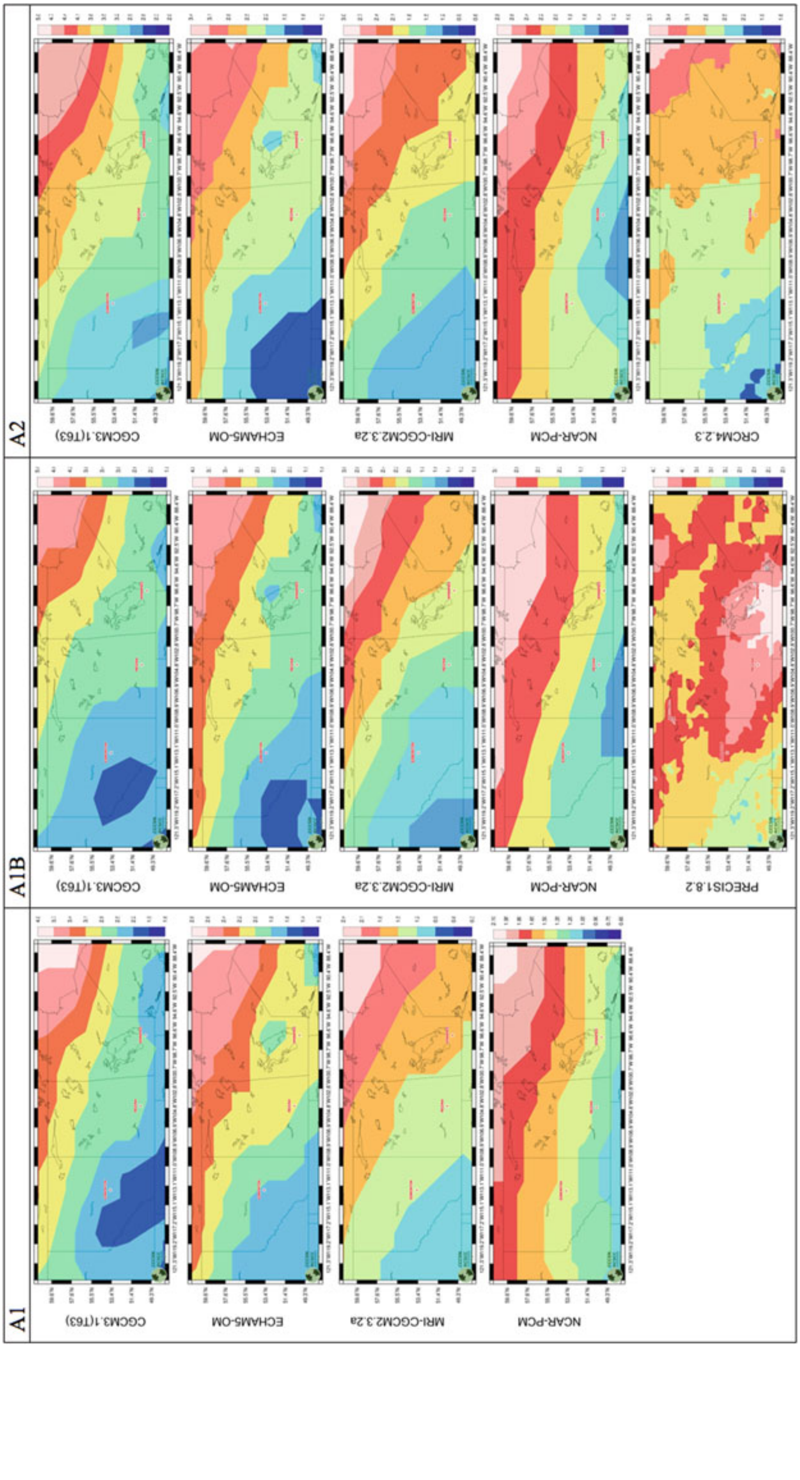

Fig. 15 Projected changes in mean annual temperatures for the 2050s (relative to 1971–2000). The climate models and SRES emissions scenarios are identified across the top and along left margin of each map

forest productivity is limited by the length of the frost-free growing season, is projections of enhanced precipitation with moderate increases in temperature and water loss by evapotranspiration. Higher productivity would result from the longer growing season, higher temperatures and concentrations of CO_2, elevated water use efficiency, and accelerated growth and maturation of crops before peak summer aridity. Higher temperatures will result, however, in potentially higher rates of evapotranspiration and, for more hours per year, cause water loss that exceeds any marginal increase in precipitation. A warmer growing season is also a more favorable environment for exotic pests, weeds, and disease vectors. These problems have technological solutions, although these technologies may be costly relative to agricultural revenues from extensive farming.

Whereas changes in average conditions can be addressed with familiar strategies, the more challenging circumstances are insufficient soil and surface water either seasonally to annually (drought) or in the longer-term (aridity) if certain thresholds are exceeded. The most severe recent drought in western Canada was during the period 1999–2003. Throughout western Saskatchewan and central and northern Alberta, most climate stations recorded the least precipitation for any single year in 2001 and for any three-year period during 2001–2003. As the impacts of drought in 2001–2002 rippled through the economies of Alberta and Saskatchewan, the loss in gross domestic product (GDP) was about $4.5 billion (Wheaton et al. 2008). A media survey by Wittrock and Wheaton (2007) showed that the most common adaptive responses were related to crops, livestock, and then water and economics. Spring and late summer were peak times for the discussion of adaptation. Innovative adaptations included water sharing agreements and modification of farming equipment. Even with considerable adaptation, negative impacts of this drought were considerable, and adaptations were costly (Wheaton et al. 2008). This suggests that some thresholds for adaptation capacity may have been exceeded for this drought. Yet the paleoclimate record, including the tree-ring reconstruction in this chapter, indicates that the worst droughts withstood by the modern economies and communities were of short duration compared to prolonged dry periods recorded by the tree rings. The greatest climate risk to the Canadian Prairies is the recurrence of drought of longer duration and/or severity than has occurred since Euro-Canadian settlement of the region.

As drought persists, soil and surface water deficits grow with increasingly serious consequences. Thus, duration is probably the key determinant of drought impacts. Nemanishen (1998) described the challenge of "Coping with Consecutive-Year Droughts":

> Modern farming technologies and practices now enable farmers to cope with single-year droughts. Most of the light lands in the drought prone areas are now either community pastures or seeded to permanent cover. Yet even with modern technologies, the current wheatlands are not able to yield sufficient returns to justify cropping in the second drought year. During the consecutive-year droughts, the precipitation deficit accumulates and leads to the depletion of the soil moisture in the root zone to a depth of a metre or more. . . . There is no technology, apart from irrigation, which can sustain either cereal grain or hay production during extended drought periods in the Palliser Triangle.

Even irrigation is ineffective under conditions of prolonged hydrological drought. Groundwater is an alternative to surface water as, in other parts of the world, it is the major source of irrigation water. However, shallow aquifers are sensitive to climate change and variability. Deeper groundwater is less responsive to climate variation, but in western Canada, it tends to be of poor quality, with high concentrations of dissolved minerals. There are few existing strategies other than government-funded assistance programs to sustain agriculture and rural communities through a drought of unprecedented duration that likely will exceed the coping capacity of prairie producers and agricultural institutions. Sustained drought, which occurred in the centuries prior to introduction of European agriculture to the Canadian Prairies, is almost certain to reoccur. The key questions are when and to what extent will global warming amplify the severity (intensity and duration). As discussed earlier in this paper, drought in western North America has been linked to large-scale anomalies in atmosphere–ocean circulation and specifically the ENSO and PDO. Thus, a scientific question of considerable relevance and intense investigation is how will the warming of the oceans and atmosphere, and the loss of arctic sea ice, modify the frequency and intensity of ENSO and the PDO and the strength of the teleconnections to regional climate variability? Even in the absence of this knowledge, we at least know that when a long and/or intense drought transpires in the coming decades it will occur in a warmer climate where demand for water from natural and human systems will be intensified.

Conclusion

Traditional cultures and economies are tied to the annual and seasonal cycles. The term ‘climate’ is from the Greek *klima* meaning inclination, referring to the sun’s declination, which varies on an annual cycle and is the cause of seasonality. Even today, as illustrated here using the case of the rural communities in the Canadian Prairies, modern economies are adapted mostly to seasonal and interannual variability, the scale with which we have the most experience. This adaptation involves familiar strategies and the corresponding policies, programs and best practices. Familiar agricultural practices include storage of water and irrigation to compensate for seasonal and interannual variability in the availability of water.

There are, however, other modes of climate variability requiring a different set of adaptations. Rural communities have less experience, and therefore fewer adaptation options, in dealing with decadal to multi-decadal modes of climate variability and with unprecedented climate extremes. These scales of climate variability and extreme events require adaptations that generally are not supported by existing policy and programming. This chapter examined decadal modes of climate variability and the adaptations required to minimize the impacts of prolonged drought and excessive moisture. If, in the short-term, natural variability continues to dominate the regional climate regime, then we should at least recognize the significance of inter-decadal variability and that there may be two sets of appropriate adaptations according to phase of the PDO, and the tempo of other teleconnections. But as we move forward through this century, the anthropogenic signal is likely to become increasingly apparent and expressed not only in terms of rising average temperatures, but also as a shift in climate variability and the severity of extreme weather events.

The most common perception of anthropogenic climate change is a monotonic upward trend in temperature resulting from a perturbation to the earth's radiative balance. This view reflects a simplified reporting of climate science and the scientific basis of climate projections – models that simulate the global response of the climate system to a change in external forcing. As important as the degree of climate changes is the timing – major climate impacts could occur with minimal changes to annual averages and totals if the distribution of heat and water shifts between seasons and years. Equating regional climate change to global warming is problematic, where changes in local temperatures and precipitation depart from the weather expected in a constantly warming world. Sun and Frank (2012) suggested, "It is time to look seriously at an alternative hypothesis, which is that the defining feature of global warming will be changes in the magnitude of climate variability." This alternative conceptualization of climate change certainly facilitates the communication and planning of adaptation in regions like the Canadian Prairies.

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Adaptation of Irrigated and Rainfed Agriculture to Climate Change: The Vulnerability of Production Systems and the Potential of Intraspecific Biodiversity (Case Studies in Italy)

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Abstract

This chapter addresses the biophysical dimension of adaptation. A framework is developed and applied to evaluate options for adaptation in different and relevant Italian agricultural cropping systems. Adaptation options rely on the identification of alternate cultivars optimally adapted to expected climate conditions, building on crops' intraspecific biodiversity. The aim is to remove or at least reduce the vulnerability of current production systems by identifying alternate cultivars optimally adapted to expected climate conditions, without altering the pattern of current species and production systems.

A new approach is proposed to (i) evaluate indicators of expected thermal and hydrologic conditions within a specific landscape and production system, (ii) identify the cultivar-specific thermal and hydrologic requirements for the optimal growth of a set of cultivars, and (iii) identify as options for adaptation the cultivars for which expected climate conditions match the climatic requirements. A robust methodology is provided to assess adaptive capacity, relying on mechanistic simulation models and on the identification of cultivar-specific climatic conditions required for optimal development and yield.

The approach is demonstrated through three case studies on (a) rainfed agriculture, (b) irrigated herbaceous crops, and (c) irrigated fruit crops. For rainfed agriculture, we have identified cultivars adapted to climate predicted for the period 2021–2050. For irrigated crops, we have evaluated adaptability for irrigation schedules ranging from optimal to severely reduced water depths. Options for adaptations of herbaceous and fruit crops have been identified as a combination of cultivars and irrigation schedules.

Keywords

Simulation models • Hydrologic requirements • Thermal requirements • Cultivars • Decision support system

Introduction: Impacts, Stressors, Vulnerability, and Adaptation

The Mediterranean Basin is currently affected by a decreasing trend in precipitation up to −15 % per decade (1979–2005), while at the same time annual temperatures are increasing in the range of 0–0.5 °C per decade, and further increases in temperature and reductions in rainfall are reported by projections of future climate change (Trenberth et al. 2007). Further, an increase in temperature variability (heat waves, precipitation extremes, increase in the number of warm spell days) has been observed in the last decade, the increase has caused reduced harvest worldwide (Tank and Konnen 2003; Coumou and Rahmstorf 2012). Impacts on agricultural crops due to reduction in water resources and increasing temperature might be larger in the Mediterranean area than in other regions (Ventrella et al. 2012).

Literature documents a lively debate about the definition of adaptation of agricultural systems particularly about the integrated assessment of climate stressors, vulnerability, and resilience toward the evaluation of climate impact on agricultural systems (Collins and Ison 2009). IPCC (2007) provides a synthesis on the assessment of impacts of climate change, the vulnerability of natural and human environments, and the potential for response through adaptation.

Several studies show that climate change is generally problematic for agricultural production economies but vulnerability can be reduced through adaptation by building upon several opportunities (Smit and Skinner 2002). Olesen et al. (2011) illustrated perceived risks and foreseen impacts on European agriculture and described observed and predicted adaptation responses.

Highlights of studies on vulnerability and adaptation of agricultural production systems are given in Table 1. In general, the approach is to measure impacts as changes in yield in response to indicators of climate variability, with the impact modulated by vulnerability. There are significant conceptual and methodological differences in the studies summarized in Table 1. However, Xu et al. (2012) defined vulnerability as having three elements: exposure (to climate stress), sensitivity, and adaptive capacity. Ventrella et al. (2012) specifically evaluated the potential of irrigation and fertilization toward the mitigation of climate impacts. Reidsma et al. (2010) evaluated the adaptive capacity of agricultural crops by comparing the yield response to spatial versus temporal climate variability. Challinor et al. (2013) reviewed predictions on the evolution of agriculture, with many studies addressing the assessment of adaptation options. Supit et al. (2012) assessed potential and water-limited yield of four selected European crops under different emission scenarios and time scales, assuming no variation in crop types. Mainuddin et al. (2013) compared the impacts on rainfed rice using different climate scenarios and evaluated specific options for adaptations to conclude that climate impacts could be offset by adaptation. Jagtap and Jones (2002) evaluated the yield response for different cultivars and planting dates but did not evaluate explicitly the relevance of such differences toward vulnerability and adaptation. Challinor et al. (2009) noted the adaptation opportunities of intervarietal differences in phenological cycle in response to the thermal regime. Meza et al. (2008) proposed double cropping as option for adaptation evaluating the introduction of new hybrids better adapted to future climate.

In this chapter, climate is regarded as an independent (external) forcing factor (i.e., stressor) with impacts being modulated by the vulnerability of each production system:

$$\text{Impact} = \text{Vulnerability} \times \text{Stressor}$$

In this logic, adaptation is an intervention aiming at reducing or removing factors of vulnerability. Options toward adaptation can include changes in currently grown crops, time of planting, irrigation management, locations, and environmental and farm management. Although there has been considerable research on farmer habits, there has been little quantitative analysis on farmers' individual adaptation decisions, especially addressing the site-specific characteristics of adaptation processes (Below et al. 2012).

The concept above has been articulated through case studies on three of the main production systems in Italy (Table 2): rainfed agriculture (grape vine and olives),

Table 1 Review of studies about vulnerability and adaptation to climate change

Author(s)	Main objectives
Ventrella et al. 2012	The impacts of predicted climate change, and the possible beneficial effects of adaptive strategies, such as irrigation and fertilization, were evaluated for winter durum wheat and tomato crop using the Decision Support System for Agrotechnology Transfer (DSSAT) v4.0 crop model
Challinor et al. 2009	GLAM model simulations were used, together with an observed data set and a simple analysis of crop cardinal temperatures and thermal time, to estimate the potential for adaptation using existing cultivars
Challinor et al. 2013	Different methods to identify geographical hot spots of vulnerability (for drought and heat stress) to climate change were illustrated. The uncertainty of predictions and assessments was evaluated by combining climate scenarios with alternate agro-meteorological models
Reidsma et al. 2010	The adaptation of farmers and regions in the European Union was analyzed to prevailing climatic conditions, climate change, and climate variability in the last decades (1990–2003) in the context of other conditions and changes. They compared (1) responses in crop yields with responses in farmers' income, (2) responses to spatial climate variability with responses to temporal climate variability, (3) farm level responses with regional level responses, and (4) potential climate impacts (based on crop models) with actual climate impacts (based on farm accountancy data)
Jagtap and Jones 2002	An operational procedure to predict soybean yield and production was developed and tested by linking the CROPGRO-soybean model with a low-resolution regional database of weather, soils, management, and cultivars. Different planting dates were considered depending on soil moisture conditions and management practices but independent on cultivars
Olesen et al. 2011	The body of knowledge on vulnerabilities of crops under present climate, estimates of impacts on selected crops, possible adaptation options, and adaptation observed so far was reviewed. Observed adaptation responses in Mediterranean environmental zones by introducing new and more suitable cultivars were documented
Meza et al. 2008	Evaluate the impacts of climate change scenarios on the productivity of two maize cultivars in central Chile using Ceres Maize in DSSAT v 4.0. They evaluate the possibility of double cropping as a response to changes in the length of the growing season
Xu et al. 2012	Explain the observed patterns of vulnerabilities also in terms of different adaptive capacities in a semiarid area of southern Alberta. They quantitatively assess the vulnerability of an agricultural system by coupling the agricultural yields with the climatic stressors

irrigated herbaceous crops (maize and tomato), and irrigated fruit crops (pears, peaches, apricots, and kiwi). They represent 48.8 % of total Italian crop productions and 37.9 % of its value (Table 2).

A very significant determinant of the vulnerability of these production systems to climate variability is the crop response to water and temperature stress (Table 3). The vulnerability of the examined cropping systems to identify option for adaptation based on the use of cultivars adapted to projected climate conditions was investigated.

Common suggestions for addressing climate change-related concerns include the use of alternate cultivars to avoid drastic changes in current production systems.

Table 2 Statistics of Italian productions of the main agricultural systems investigated in this study (After FAOSTAT 2011 http://faostat.fao.org/site/339/default.aspx)

Production system	Crops	Value (% of total)	Production (% of total)	Value ($\$ \cdot 10^6$)	Production ($t \cdot 10^3$)
Rainfed agriculture	Olives	20.9 %	17.2 %	2,548	3,182
	Grapes			4,067	7,116
Irrigated herbaceous crops	Maize	11.3 %	26.2 %	1,382	9,753
	Tomatoes			2,199	5,950
Irrigated fruit crops	Pears	5.6 %	5.4 %	379	927
	Peaches			891	1,637
	Apricots			145	263
	Kiwi fruit			352	431
Total		37.8 %	48.8 %	11,963	29,259

This approach relies on the significant intraspecific differences of resilience to climate-related stresses (Reyer et al. 2013).

In Europe, Italy has the largest number of plant species; for instance, the biodiversity of Italian vegetable crops consists of 36 crops with 1,512 cultivars (nearly 8 % of total in Europe) (Elia and Santamaria 2013). Hundreds of cultivars of olive and grape vine are cultivated across a very broad range of climates worldwide; this implies a very significant potential for the adaptation of these production systems in Italy. It must be noted that adaptation by substitution of current cultivars leads to potential impacts on the current system of certification of high-quality types of oil and wine, which are linked to the current location of cultivars.

As regards irrigated agriculture, adaptation may be achieved through changes in irrigation management if water is not a limiting factor. Contrariwise, in a scenario of reduced water resources, intraspecific differences in yield response to water availability become as important as in rainfed agriculture. Moreover, management practices can be tuned to take advantage from regulation of plant development, which may increase water use efficiency. Reduced amounts of water may be applied to some crops to exploit the plant stress-sensing capacity to reduce unnecessary vegetative growth while maintaining fruit production with a reduced supply of water (Davies et al. 2002; Girona et al. 2005).

Intraspecific Biodiversity of Agricultural Crops: A Toolkit to Identify Options for Adaptation

Overview

A new approach has been developed to identify options for adaptation, which avoids the assessment of climate impacts on agricultural yields and does not aim at adaptation by mitigating impacts on current cropping patterns. Instead, the aim is to remove or at least reduce the vulnerability of current production systems by

Table 3 Crop responses to water and temperature stress

		Stressors	
		Water deficit	High/low temperature
Dry land agriculture	Olive	Olive is well known to be very resistant to drought (Bongi and Palliotti 1994; Giorio et al. 1999; Tognetti et al. 2004; Connor 2005), and the crop achieves acceptable yields while subjected to high irradiance and temperature and to prolonged water shortage	Excessive temperatures can negatively influence several reproductive processes (flower development, pollen viability, and the pollination process) and, consequently, fertilization and yield (Aguilera et al. 2013)
		The species has developed efficient physiological, biochemical, and morphological mechanisms of drought avoidance and tolerance. Avoidance involves mechanisms to reduce transpiration and to maintain root water uptake and high plant water potential as drought sets in. Other mechanisms increase tolerance to dehydration at low plant water potential as the drought deepens (Connor and Fereres 2005)	
		Significant yield differences among cultivars have been observed under drought conditions (Chartzoulakis et al. 1999)	
	Grapevine	Severe water deficit results in low sugar concentration as a consequence of restricted carbon assimilation (Matthews and Anderson 1988; Santesteban and Royo 2005). However, mild to moderate water deficit results in higher sugar level in fruits and in earlier ripening (Roby et al. 2004)	Heat stresses (T_{max} > 35 °C) during berry ripening are associated with lower photosynthesis rates and yield. High temperatures affect yield's quality and quantity through reduced fruit set and berries' size (Kliewer 1977); color development (Kliewer and Torres 1972) and of flavor ripening (Mullins et al. 1992) are inhibited, as well
		In Mediterranean climate, water stress in spring and early summer up to the beginning of ripening should be avoided. Restricted water availability in a later stage favors berry ripening by limiting late vegetative growth (Jackson 2008). Bonfante et al. (2012) showed a positive correlation between water stress occurring in the berry formation phase and wine quality (i.e., content of anthocyans, polyphenols, sugar, and titratable acidity)	

(*continued*)

Table 3 (continued)

		Stressors	
		Water deficit	High/low temperature
Irrigated herbaceous crops	Tomato	Water availability affects flower formation and fruit size. Water stress decreases the average number of flowers per truss and can severely reduce fruit set. Moreover, low water availability concurs in causing physiological disorders (e.g., blossom-end rot) (Kinet and Peet 1997)	High temperatures (36–40 °C) adversely affect the reproductive process, causing abscission of flowers or young fruits. At ripening, temperatures above 30 °C inhibit lycopene synthesis and may cause fruit disorders (e.g., sunscald) (Kinet and Peet 1997)
	Maize	Maize is very sensitive to drought at flowering (Otegui et al. 1995). NeSmith and Ritchie (1992) reported yield reductions over 90 % caused by water deficit during flowering	Warmer growing season can directly reduce yields. Heat stress in combination with drought is a common constrain during the anthesis and grain filling stages. The ability of pollen to germinate on silks is greatly reduced at temperatures above 32 °C (Basra 2001)
Irrigated fruit crops	Peach	Peaches are sensitive to water stress during some phenological phases, like flowering and fruiting (Xiloyannis et al. 2005)	Peach is very sensitive to spring frosts that can completely destroy fruit production (Steduto et al. 2012). Peach requires an appropriate thermal sequence (in terms of occurrence and level of high/low temperatures) for a proper formation of reproductive organs (Couvillon and Erez 1985)
	Pear	Pear's organs and tissues can withstand a certain degree of dehydration; thus, this species exhibits a drought resistance higher than other deciduous fruit trees such as peach, plum, or apple. Moderate water stress during the fruit-growing season or postharvest increases flowering in the following season (Naor 2006)	In pear higher temperatures accelerate the development of disorders like watercore (Sakuma et al. 1995)

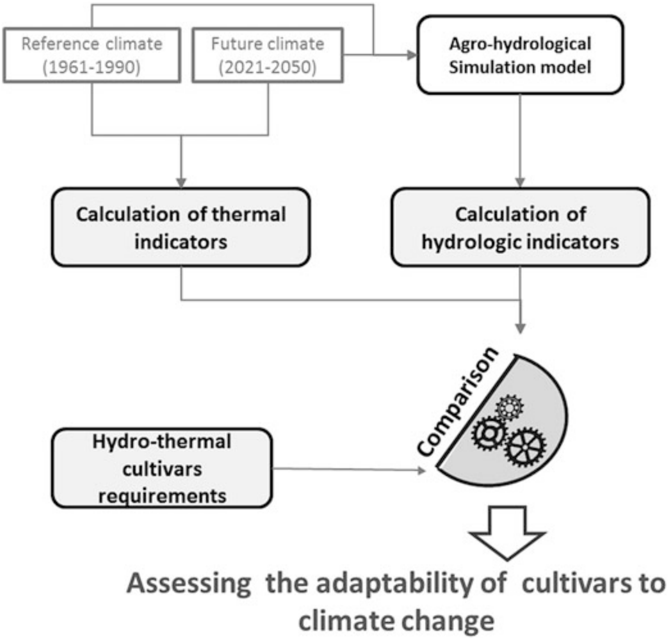

Fig. 1 Conceptual scheme of proposed approach to assess the adaptability of cultivars to climate by evaluating climate indicators against cultivar-specific climatic requirements

identifying alternate cultivars optimally adapted to expected climate conditions, without altering the pattern of current species and production systems (Menenti et al. 2008; De Lorenzi et al. 2013b).

The approach involves the following steps (Fig. 1):

(i) Evaluate indicators of expected thermal and hydrologic conditions within a specific landscape and production system.
(ii) Identify the thermal and hydrologic conditions required for the optimal growth of a set of cultivars relevant to the production system under consideration, i.e., cultivar-specific climatic requirements.
(iii) Identify the cultivars for which expected climate conditions match the climatic requirements (options for adaptation).

With this approach, options for adaptation have been evaluated in different Italian agricultural systems (Fig. 2 and Table 2) that are representative of the most important production systems: (i) a valley dominated by grape vine and olive orchards, with a significant presence of wheat (Valle Telesina); (ii) an irrigated district where cereals and horticultural crops are grown (Destra Sele); and (iii) an area of the Po Valley where fruit crops are intensively grown (Romagna).

Models of crop response to environmental forcing might be used for the evaluation of crop adaptability but are severely constrained by the very scarce knowledge

Fig. 2 Location of the investigated study areas within the Italian territory

on cultivar-specific values of model parameters (Craufurd et al. 2013), thus limiting analyses toward the potential exploitation of intraspecific biodiversity for adaptation. More robust assessments of adaptive capacity are achieved by relying on cultivar-specific climatic conditions required for optimal development and yield, as described in this chapter.

Downscaled climate scenarios have been used (Tomozeiu et al. 2014) to calculate indicators of soil water availability and thermal times and to evaluate the variability of crop phenology in combination with critical temperatures.

Cultivar-specific thermal requirements defining timing of each phenological stage have been estimated by combining phenological observations on different cultivars with the calculation of crop- and phase-specific thermal times. Critical temperatures have been determined on the basis of scientific literature and used to assess thermal hazard in different phenological stages (Fig. 3). The requirements on water availability of several cultivars for each dominant species in each production system have been derived from yield response functions to water availability through the reanalysis of experimental data sets.

Next, to identify options for adaptation, the compatibility of such requirements with the thermal and hydrologic conditions was characterized using the indicators mentioned above in a reference (current) and a future climate case. As regards hydrologic conditions, this compatibility assessment has been done at landscape scale in all soil units within each study area (Fig. 4). This has lead to maps of

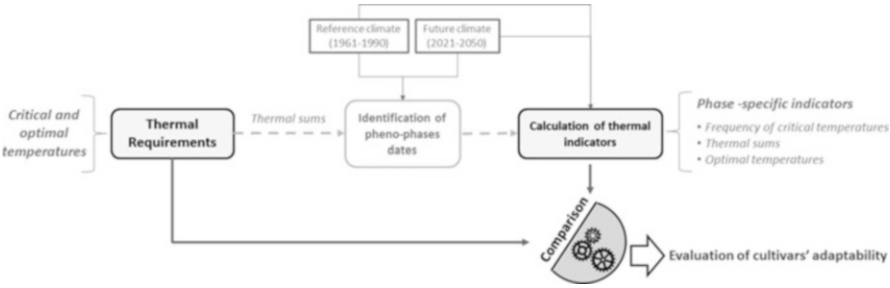

Fig. 3 Schematization of the procedure to evaluate adaptability on the basis of thermal requirements

locations where each crop is expected to be compatible with climate. When dealing with irrigated agriculture, different irrigation water management options were considered. Timing of phenological phases in both climates (reference and future) has been determined to evaluate the compatibility of the cultivars with the thermal regime (Fig. 3). The combination of these procedures has lead to identify both potential crop persistence and cultivar substitutions within the areas.

Climate. Two climate scenarios were considered: reference (1961–1990) and future (2021–2050) climate, the former from climatic statistics on observed variables and the latter from statistical downscaling of general circulation models (AOGCM). Climatic data consist of daily time series of maximum and minimum temperature and daily rainfall on a grid with a spatial resolution of 35 $\times$ 35 km (Villani et al. 2011; Tomozeiu et al. 2014).

Thermal indicators. Three types of thermal indicators have been used: (a) dates of occurrence of phenological phases for each year and for each cultivar, calculated by using cultivar- and phase-specific thermal requirements; (b) mean air temperature in a crop-specific period of time (optimal temperatures); and (c) extreme temperatures (critical) associated with severe impact on crop metabolism and yield.

Hydrologic indicators. The mechanistic model SWAP (soil–water–atmosphere–plant model) of water flow in the soil–plant–atmosphere system was used (Fig. 4) to describe the hydrologic conditions in response to climate and irrigation. In most areas, the model was calibrated and validated for the different crops. Crop-specific input data and model parameters were estimated on the basis of local experiments and of scientific literature and assumed to be generically representative of the species. The yearly time series for the reference and future climate were used as climate forcing. The soil hydraulic properties were estimated by means of pedotransfer functions as implemented in the HYPRES (hydraulic properties of European soils) database (Wösten et al. 1999) and measured on undisturbed soil samples in some cases (Basile et al. 2006). For irrigated crops, different irrigation scheduling options were simulated. Two indicators of soil water availability have been calculated using the numerical experiments: the relative soil water deficit ($RSWD_{soil}$) and the relative evapotranspiration deficit ($RETD_{soil}$) (De Lorenzi et al. 2010; Monaco et al. 2012; Alfieri et al. 2013b; Bonfante et al. 2013;

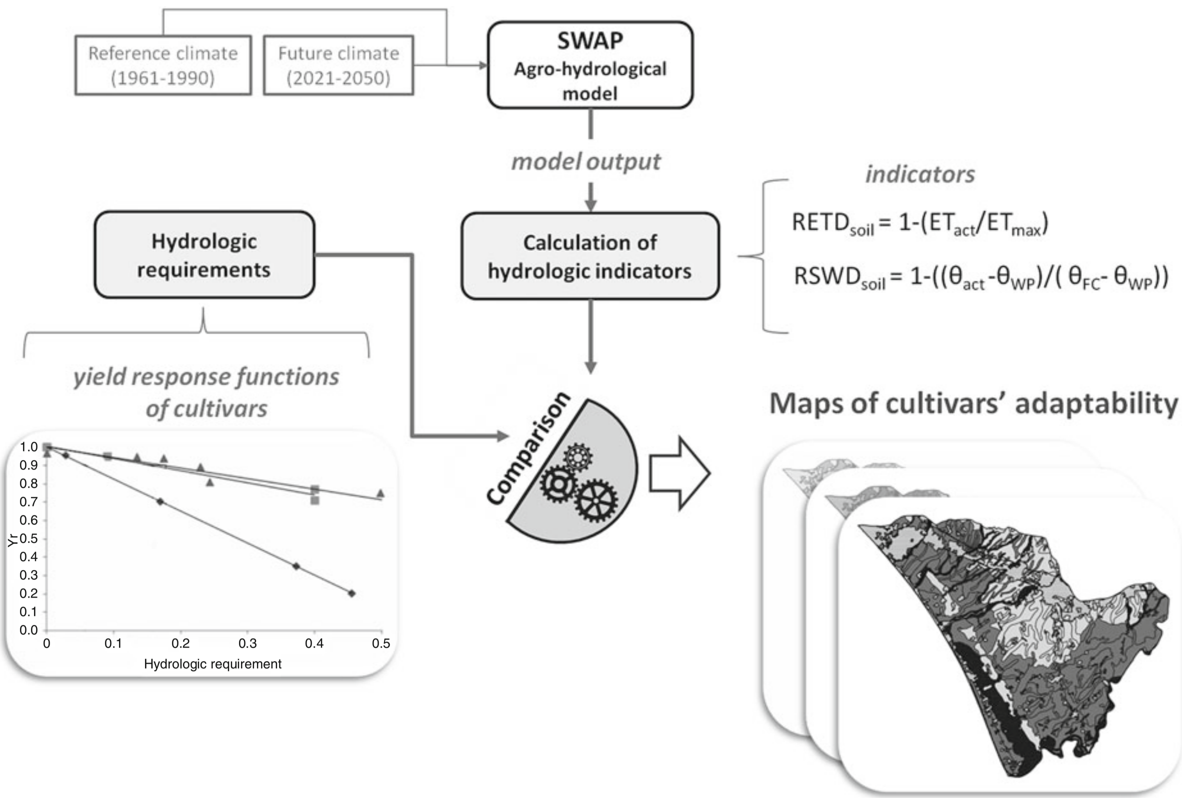

Fig. 4 Schematization of the procedure to evaluate adaptability on the basis of hydrologic requirements

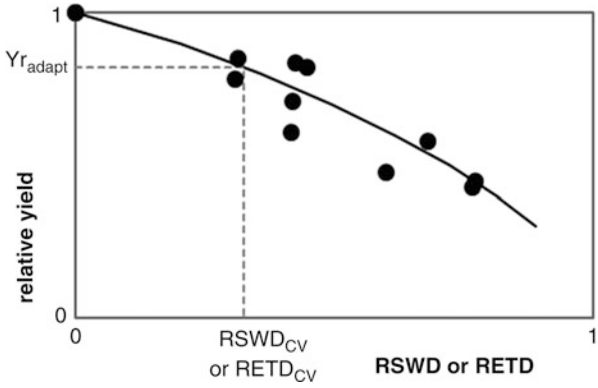

Fig. 5 Relative yield as a function of soil water availability indicators: relative soil water deficit (RSWD) or relative evapotranspiration deficit (RETD). The relative yield desirable for adaptation (Yr_{adapt}) and the corresponding values of the indicators ($RSWD_{cv}$ or $RETD_{cv}$) are shown

De Lorenzi et al. 2013a; Reyer et al. 2013). Daily values of these indicators were calculated for each soil unit.

Crop Climatic Requirements

Thermal requirements. Variety-specific phenology is used as a biological indicator to evaluate adaptability to the thermal regime. Three types of thermal requirements have been used: (a) thermal time required for completion of a specific phenological stage, (b) mean temperature required in a specified period of time, and (c) extreme minimum and maximum temperature, beyond which crops do not recover from thermal stresses.

Hydrologic requirements. Cultivar-specific hydrologic requirements have been derived from yield response functions to water availability for both irrigated and not irrigated crops (Fig. 5). The critical values of the indicators, namely, $RSWD_{cv}$ and $RETD_{cv}$, were defined by setting a threshold (acceptable) yield level. The required information was obtained from the reanalysis of experimental data sets, from both local experiments and scientific literature.

Adaptability Assessment

To identify which cultivars are adapted to expected thermal and hydrologic conditions, the thermal and hydrologic indicators have been evaluated against the cultivar-specific thermal and hydrologic requirements and the associated statistics. This evaluation has been repeated for multiple realizations of each climate case, and estimated probabilities have been associated with statements on the compatibility of a cultivar with expected thermal and hydrologic conditions.

The evaluation of hydrologic conditions ($RSWD_{soil}$ and $RETD_{soil}$) against hydrologic requirements ($RSWD_{cv}$ and $RETD_{cv}$) has been carried out for each soil unit within a study area, leading to soil-specific statements on adaptability.

For irrigated crops, cultivar adaptability was evaluated in relation with the hydrologic indicators corresponding to different irrigation scheduling options.

The evaluation of thermal conditions against thermal requirements has been carried out initially by comparing required mean temperatures with mean temperatures over the same period of time for all available yearly time series (reference and future climate). The dates of each phenological stage for each variety and each year have been estimated, and then the frequency of temperature extremes during critical phases, e.g., flowering and fruit formation, was evaluated. In a similar way as with hydrologic conditions, estimated probabilities of the compatibility with variety-specific requirements have been associated with expected thermal conditions.

Designing Adapted Production Systems with Data and Models

Climate Cases

Daily air temperature and precipitation time series for the reference and future climate scenarios have been produced within the Italian project "Agroscenari" (www.agroscenari.it). Data are available over a 35 × 35 km-resolution grid covering the entire Italian territory. The database consists of:

– Reference climate case, i.e., the period 1961–1990
– Future climate case consisting in 50 realizations of a year representative of the period from 2021 to 2050

Reference climate case. The reference climate has been produced by the "Unità di Ricerca per la Climatologia e la Meteorologia applicate in Agricoltura" (CRA-CMA) applying the "kriging with external drift" method (Wackernagel 1998) to the meteorological data included in the National Agro-meteorological Database (http://cma.entecra.it/Banca_dati_agrometeo/index3.htm). Daily meteorological data have been gridded at 35 × 35 km resolution for the period from 1950 onward (Esposito 2010; Table 4).

Table 4 Annual mean and standard deviation (in parenthesis) of meteorological variables at the reference nodes for each study area over the reference period (1961–1990) and future climate scenario (2021–2050)

	T_{min} (°C)		T_{max} (°C)		Rainfall (mm)	
	1961–1990	2021–2050	1961–1990	2021–2050	1961–1990	2021–2050
Valle Telesina	8.70 (0.40)	10.17 (0.28)	18.73 (0.51)	20.43 (0.33)	1069 (212)	912 (100)
Destra Sele	10.24 (0.38)	11.53 (0.28)	19.79 (0.53)	21.37 (0.28)	1035 (178)	838 (122)
Romagna	9.04 (0.37)	10.28 (0.30)	17.72 (1.05)	19.35 (0.40)	701 (133)	708 (110)

Future climate case. Daily values of maximum and minimum temperatures as well as precipitation data have been produced in two phases. At first the seasonal mean and standard deviation of the meteorological variables have been generated by a statistical downscaling model (SDM, Tomozeiu et al. 2007) starting from coupled atmosphere–ocean global climate models (AOGCMs) under emission scenario A1B (ENSEMBLE, Van der Linden and Mitchell 2009). The results are then used by a weather generator to produce 50 realizations of the daily values of the same variables for a year taken as representative of the period between 2021 and 2050. The work was carried out by the "Agenzia Regionale per la Protezione Ambiente" (ARPA-SIM) within the project Agroscenari (Tomozeiu et al. 2014; Table 4).

Hydrologic Indicators

Water balance analysis was performed using the SWAP model (Kroes et al. 2008). Assuming 1-D vertical flow processes, it calculates the soil water flow by integrating the Richards' equation:

$$C(h) \cdot \frac{\partial h}{\partial t} = \partial \left[k(h) \cdot \left(\frac{\partial h}{\partial z} + 1 \right) \right] \cdot \partial z - S(h) \tag{1}$$

where $C(h) = \partial\theta/\partial h$ is the soil water capacity, θ (cm^3 cm^{-3}) is the volumetric soil water content, h (cm) is the soil water pressure head, t (d) is the time, z (cm) is the vertical coordinate taken positively upward, k (cm d^{-1}) is the hydraulic conductivity, and S (cm^3 cm^{-3} d^{-1}) is the water extraction rate by plant roots.

Soil water retention is described by the unimodal $\theta(h)$ relationship proposed by van Genuchten (1980) and expressed here in terms of the effective saturation, Se, as follows:

$$Se = \left[\frac{1}{1 + (\alpha|h|)^n} \right]^m \tag{2}$$

with $Se = (\theta - \theta_r)/(\theta_0 - \theta_r)$, θ_r and θ_0 being the residual water content, respectively, the water content at $h = 0$, where α (cm^{-1}), n, and m are curve-fitting parameters.

Mualem's expression is applied to calculate relative hydraulic conductivity, k_r (Mualem 1976). Assuming $m = 1 - 1/n$, van Genuchten (1980) obtained a closed-form analytical solution to predict k_r at a specified volumetric water content:

$$k_r(Se) = \frac{k(Se)}{k_0} = Se^{\tau} \left[1 - \left(1 - Se^{1/m} \right)^m \right]^2 \tag{3}$$

where k_0 is the hydraulic conductivity at θ_0 and τ is a parameter which accounts for the dependence on the tortuosity and partial correlation between adjacent pores.

The condition at the bottom boundary can be set in several ways (e.g., pressure head, water table, fluxes, impermeable layer, unit gradient, etc.).

The upper boundary conditions when applying SWAP to agricultural crops are generally described by the potential evapotranspiration ET_p, irrigation and daily precipitation. SWAP simulates water uptake and actual transpiration according to the model proposed by Feddes et al. (1978), where root water uptake S is a function of the pressure head, h:

$$S(h) = \alpha(h) \cdot S_{\max} = \alpha(h) \cdot \frac{T_p}{|z_r|} \tag{4}$$

being z_r (cm) the thickness of the root zone and $\alpha(h)$ a semiempirical function of pressure head h, varying between 0 and 1. The shape of the function $\alpha(h)$ depends on four critical values of h, which are related to crop type and to potential transpiration rates. The actual transpiration rate T_a (cm d^{-1}) is computed by the integration of S over the root layer. The root depth is specified by the user as function of development stage.

The dependence of soil hydraulic properties on soil texture (Wösten et al. 1999) was established by making use of the HYPRES database (http://www.macaulay.ac.uk/hypres/) and evaluated against a limited number of measured water retention and hydraulic conductivity functions. It is this simple yet robust relationship between soil texture and van Genuchten parameters that makes this approach feasible to study large and complex landscapes.

The soil–water–atmosphere–plant model (SWAP) was applied to solve the soil water balance in both climate cases for each soil unit in the case study areas (Fig. 4). The ET_p was calculated by means of the Hargreaves and Samani (1985) formula and a crop coefficient.

Irrigation scheduling. In the case of irrigated agriculture, climate signatures and options for adaptation are strongly dependent on irrigation strategies. Six irrigation strategies have been evaluated for each climate scenario and for each soil using the model SWAP, i.e., optimal irrigation; 80 %, 60 %, 40 %, and 20 % of optimal water depths; and no irrigation. At first, the optimal irrigation schedule under the constraint that actual transpiration be equal to potential transpiration at all times has been calculated: this yields dates and water depths.

Next, increasing reductions have been applied to water depths keeping the same dates as in the optimal irrigation schedule. Finally, the hydrologic indicators and the effectiveness for each irrigation schedule was evaluated (De Lorenzi et al. 2013a).

Indicators were calculated from simulation runs in all soil units, to describe soil water availability. Namely, the relative soil water deficit (RSWD) and the relative evapotranspiration deficit (RETD) were determined, as follows:

$$\text{RSWD} = 1 - \frac{\theta_{act} - \theta_{WP}}{\theta_{FC} - \theta_{WP}} \tag{5}$$

where θ (m^3 m^{-3}) is the volumetric soil water content in the layer explored by roots, namely,

θ_{act} = actual soil water content
θ_{WP} = soil water content at $h = -1{,}500$ kPa (wilting point)
θ_{FC} = soil water content at $h = -33$ kPa (field capacity)

$$\mathrm{RETD} = 1 - \frac{ET_{act}}{ET_{\max}} \tag{6}$$

where
ET_{act} = actual crop evapotranspiration (mm)
$ET_{\max}$ = maximum crop evapotranspiration (mm), i.e., evapotranspiration at optimum soil water availability

Thermal Indicators

The response of plants to both mean and extreme temperature varies very significantly across phenological stages, and it is a well-established notion that plant development scales with thermal rather than actual time (Lawler et al. 2010). This concept has been applied to model the response to climate of global and continental vegetation (Huang et al. 2010). Accordingly, a three-tiered approach to characterize thermal conditions is applied:

– Calculate specific thermal times for each phenological stage.
– Calculate mean air temperature for each phenological stage.
– Calculate the frequency of extreme low and extreme high temperatures during the phenological stages most sensitive to either extreme conditions.

Thermal times. The start and end dates of each phenological stage have been estimated by matching cultivar- and phase-specific thermal requirements, as described below, with thermal times. Thermal time, expressed in terms of growing degree days (GDD) or growing degree hours (GDH), is calculated by means of phase-specific models forced from mean air temperature.

Mean air temperature. During specific phenological phases, e.g., ripening, mean air temperature is a significant determinant of the quantity and quality of yield. A notable case is grape vine with stringent cultivar-specific requirements (e.g., Jones 2006) identifying optimal conditions for growing a specific cultivar. Given the timing of phenological stages, estimated for each year of both the reference and future climate cases, mean air temperature for each phase is calculated.

Extreme temperatures. During early phenological stages, e.g., bud swelling and flowering, extremely low temperatures can halt crop development irrecoverably. Likewise, extreme high temperatures during ripening can compromise crop yield. Accordingly, the frequencies of air temperature lower than a minimum and higher than a maximum phase-specific threshold for each year, of both the reference and future climate cases, were calculated.

Determination of Cultivar-Specific Hydrologic and Thermal Requirements

Cultivar-specific *hydrologic requirements* were determined for many cultivars of the most representative crops of the selected case studies. Requirements were determined through the reanalysis of experimental data sets derived from scientific literature. To this purpose, the yield of each cultivar was expressed as a function of soil water availability measured by either RSWD or RETD.

The crop yield was expressed as relative yield (Yr) defined as:

$$Yr = \frac{Y_{act}}{Y_{\max}} \tag{7}$$

where

Y_{act} = actual yield

$Y_{\max}$ = maximum yield under given climate and soil conditions, i.e., the yield at optimum soil water availability

The relations between relative yield and soil water availability indicators were determined rearranging existing experimental data sets. Yr values were plotted against values of water availability indicators, and the yield response function was defined by a curve fitting to experimental data. A generic yield response function is shown in Fig. 5.

The level of relative yield below which yield reduction is unacceptable was thus identified for each cultivar and indicated as the set point for adaptation (Yr_{adapt}).

The value of the indicator (RSWD or RETD) corresponding to Yr_{adapt} was set as the cultivar-specific hydrologic requirement (RSWD_{cv} or RETD_{cv}). An error of estimation, due to the empirical relationship between Yr and soil indicators, was associated to each RSWD_{cv} (or RETD_{cv}).

Hydrologic requirements are summarized in Table 5 where values of RSWD_{cv} and RETD_{cv} span quite different ranges, between different species and also within the same species e.g., olive. Cultivar requirements, determined in a certain phase of crop cycle, were evaluated against hydrologic conditions calculated, by means of the simulation model, in the corresponding time period.

Thermal requirements. Required *thermal times* for completion of each phenological phase and for each cultivar are calculated starting from multiannual observations of start and end dates of occurrence of the phenological phases and the thermal times calculated as outlined above. In some cases, the Chilling requirements have been derived from the technical specifications of each cultivar provided by the producers. An example of phase-specific thermal time calculation for peach crop is summarized in Table 6 where the phases and the models used to calculate thermal requirements and the corresponding units of each considered thermal time are listed.

The dates of occurrence of each phenological phase were estimated by matching the calculated phase-specific thermal times with the thermal requirements for each cultivar and for each year for both the reference and the future climate cases.

Table 5 Range of hydrologic requirements across cultivars relevant to the productions systems of the three case studies

Area	Crops	$RSWD_{cv}$ range	$RETD_{cv}$ range
Valle Telesina	Olive (11 cv)	0.47–0.73	0.32–0.39
Destra Sele	Tomato (4 cv)	0.41–0.54	
	Maize (5 hybrids)		0.03–0.50
Romagna	Peach (2 cv)	0.29–0.30	

Table 6 Overview of thermal times used to estimate the dates of start and completion of phenological phases for peach cultivars

Phase	Thermal times model	Unit	References
Rest	Richardson chill unit	Chilling units (CU)	Richardson et al. 1974
Bud development and inflorescence emergence	North Carolina	Growing degree hours (GDH)	Shaltout and Unrath 1983
Flowering	Growing degree days	Growing degree days (GDD)	Bonhomme 2000
Fruit development	Growing degree days	Growing degree days (GDD)	Bonhomme 2000
Ripening	Growing degree days	Growing degree days (GDD)	Bonhomme 2000

Mean air temperature. Literature documents well-defined ranges of mean air temperature during specific phenological stages which identify optimal, cultivar-specific climatic conditions (e.g., Jones 2006; Mariani 2008). A data set on the optimal mean air temperature for a number of grapevine cultivars has been compiled and applied to identify suitable areas for each cultivar in the reference and future climate cases.

Extreme temperatures. Literature on critical low and high temperature during specific phenological stages was reviewed and compiled. The requirement applied was that such critical temperatures must not be exceeded. The frequency of occurrence of such events, estimated as described above, was used to assess the probability of irrecoverable impacts on crop development.

Assessing the Design by Measuring Adaptability

The Hierarchy of Criteria for Adaptability

Thermal requirements are critical determinant of adaptability since in case climatic conditions are not compatible with a cultivar thermal requirement, the crop under consideration will suffer severe impact on metabolism and yield, making hydrologic requirements irrelevant. To assess adaptability of a given variety, therefore, it is needed to assess whether expected climate meets the requirements by considering stressors in the following sequence:

1. Duration and dates of phenological phases
2. Mean temperature in specific phenological phases
3. Extreme temperature in specific phenological phases
4. Water deficit

Probabilistic Assessment of Adaptability

The assessment of adaptability is performed by evaluating whether the value of stressor indicators (S_i) is lower than requirements (R_i). The estimates of such requirements, however, are affected by a standard error of estimate (δ_{Ri}*) that needs to be taken into account. The error on the estimated R_i^m is indicated as a random variable δ_{Ri} with a normal distribution of standard deviation δ_{Ri}*.

Requirement R_i is therefore:

$$Ri = R_i^m + \delta_{Ri} \tag{8}$$

where R_i^m is the requirement estimated by experimental data and δ_{Ri} its associated standard error.

The probability distribution function of the requirement is:

$$f(R_i) = R_i^m \pm \frac{1}{\delta_{Ri}{}^* \sqrt{2\pi}} e^{-(Ri - Ri^m)^2 / 2\delta_{Ri}{}^{*2}} \tag{9}$$

When evaluating the adaptability for a specific cultivar in a specific year and environment, the uncertainty of the requirement estimation is taken into account by calculating the probability (P) that given a random value of the requirement (according to Eq. 9), the stressor indicator for that year (in a certain phase) is lower than the requirement value (Fig. 6).

The distribution over the reference and future climate of the probabilities calculated as explained above is evaluated. Medians M of P (over the years in either scenario) are then used to assess and quantify the adaptability of cultivars, and its spatial distribution, in the reference and future climate.

The Climate Adaptation Information System (CAIS)

The calculation of the thermal and hydrologic indicators for the production systems and environmental and climatic conditions examined in this study requires the following tools (Fig. 7) based on the modeling approach described above:

Development of an information system and of a user interface for modeling engine based on the SWAP code (3.2.26 version porting for LINUX operating system, http://www.swap.alterra.nl) by using different climate forcing. This step is based on an automatic procedure to run the model iteratively with different crop,

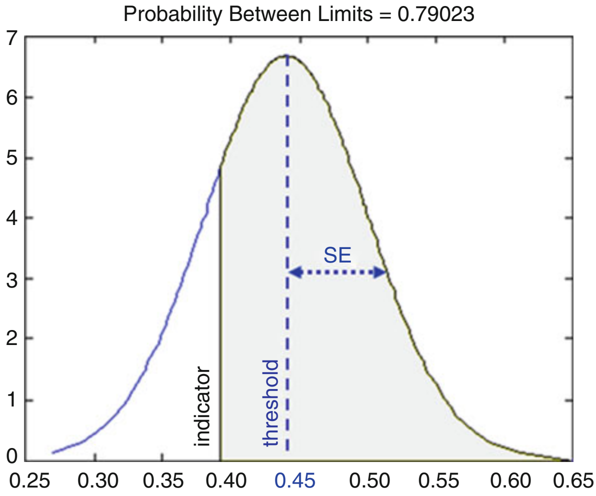

Fig. 6 Probability distribution function of the estimated requirement. *Shaded area* indicates the probability P that the (thermal or hydrologic) indicator is lower than the threshold requirement

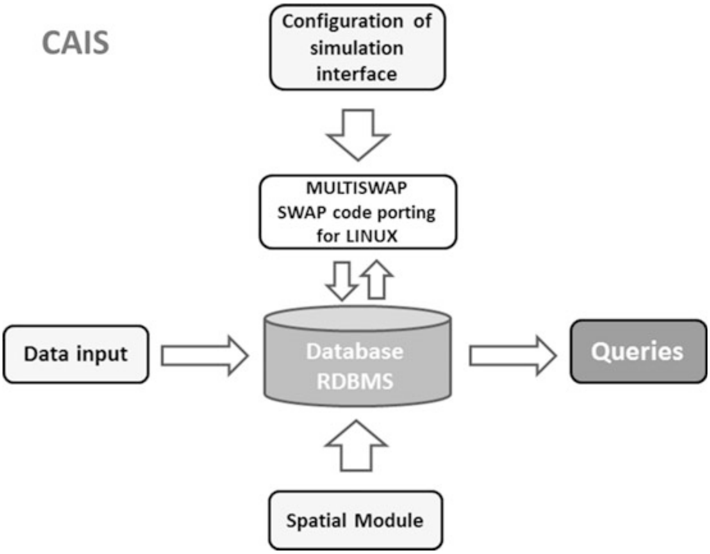

Fig. 7 Simplified scheme of the Climate Adaptation Information System (CAIS)

soil data, and meteorological input data. The system (called MultiSWAP) allows to execute the SWAP model for all custom calculation cells which have been identified in the study areas. It provides a configuration panel to design and execute all the simulations in one run.

Architecture of the database and of the procedures to populate it. Crop, meteorological, and soil data for the areas under study can be available in different formats, i.e., tables and vector formats (points and polygons). This step is based on

GIS (geographical information system) procedures to process and harmonize the different input data sets to the format required by the first step. In particular, spatial interpolation of point variables (i.e., meteorological data) and intersection of vector and raster layers are necessary. A specialized spatial interpolation module to interpolate meteorological data based on GStat code (Pebesma and Wesseling 1998) has been implemented.

Procedures and algorithms for data query and analysis on the output database to generate the required indicators, accordingly to user-defined criteria. They allow to (i) perform calculations on outputs, (ii) aggregate outputs on spatial and temporal scale, (iii) calculate statistics on the matching between user-defined requirements and simulated values, and (iv) display on a web interface the results of geo-located queries on maps.

The information system is based on an automated web infrastructure (Fig. 7).

Case Studies

The approach described above has been applied and refined by carrying out three case studies (Table 7).

Case Study 1: Valle Telesina

The "Valle Telesina" is a 20,000 ha complex landscape located in South Italy in the Campania region, which has a complex geology and geomorphology, and it is characterized by an E–W elongated graben where the Calore River flows. The valley is surrounded on both the Southern and Northern sides by the Matese massif. Camposauro Mountain is the dominant relief that reaches up to 1,390 m asl. The main crops are grapevine (6,448 ha) and olive (3,390 ha).

Vulnerability challenges. Olive (*Olea europaea* L.) is a typical sclerophyllous species, native plant in the semiarid Mediterranean climate. During the last 500 years, olive growing has extended all over the world but remains mainly a crop of the Mediterranean Basin (Connor 2005). In this area, olive is generally cultivated in rainfed conditions under the minimum viable rainfall and therefore

Table 7 Overview of case studies

Cropping system	Area	Ha	Lat long	Crops	Environment
Rainfed agriculture	Valle Telesina	20,000	41 N, 14E	Olive, grapevine	Hilly region
Irrigated herbaceous crops	Destra Sele	22,000	40 N, 14E	Maize, tomato	Coastal plain
Irrigated fruit crops	Romagna	20,000	44 N, 11E	Fruit crops (peach, apricot, pear, kiwifruit)	Plain

Table 8 Thermal requirements of grapevine varieties estimated using concurrent phenological observations and climate data in the period 1992–2003 (Scaglione et al. 2008)

Grapevine varieties	Thermal requirements	Ranges
Fiano	1625	1575–1625
Trebbiano tosc.	1650	1625–1675
Falanghina	1736	1711–1761
Aglianico	1804	1779–1829
Catalanesca	1865	1840–1890
Malvasia di Candia	1880	1855–1905
Forastera	1950	1925–1975
Guarnaccia	1980	1955–2005

vulnerable to climate variability and change, particularly to amount and distribution of precipitation. The adaptability of 11 olive cultivars was evaluated using hydrologic indicators and requirements.

Grapevine (*Vitis vinifera* L.) is cultivated all over the world mainly in rainfed conditions but also with irrigation and supplemental irrigation practices. This crop is very sensible to environmental conditions (soil type, thermal regime, water availability), particularly as regards grape and wine quality (sugar, acidity, polyphenols, anthocyans, etc.). Soil water availability in response to climate is strongly dependent on soil type (Bonfante et al. 2011, 2012).

Thermal regime largely influences which cultivar may better adapt to climate (Amerine and Winkler 1944), since it is a strong driver of metabolism (Kriedman 1968; Seguin and Cortazar 2005). Generally, grapevine shows a very selective adaptation to the temperature regime during fruit formation and ripening stage. The quality of grapes and wine is strongly dependent on mean air temperature, and ranges of average growing season temperatures are known (Jones 2006).

Thermal indicators. This case study was focused, as regards grapevine, on mean air temperature during the growing season (April–October). Given the morphology of the study area, the spatial distribution of mean air temperature must be determined. The dependence of air temperature on elevation was determined by regression analysis and applied to downscale air temperatures over the study area. At a later stage, a new method was developed using time series of MODIS TIR data to downscale gridded climate data on air temperature (Alfieri et al. 2013a).

Thermal requirements of nine grapevine cultivars, typical of the Campania region, are shown in Table 8, as defined using the Amerine and Winkler index (AWi). The latter was calculated as:

$$AWi = \sum_{DoY=91}^{DoY=304} T_m - 10 \tag{10}$$

where T_m is the mean air temperature.

The probability distribution of the stressor (thermal time) was estimated from observed frequencies for the two climate cases (1961–1990 and 2021–2050). Then the integral of the distribution within the ranges defined by thermal requirements was calculated to evaluate the probability of adaptation (shaded bar in Fig. 8).

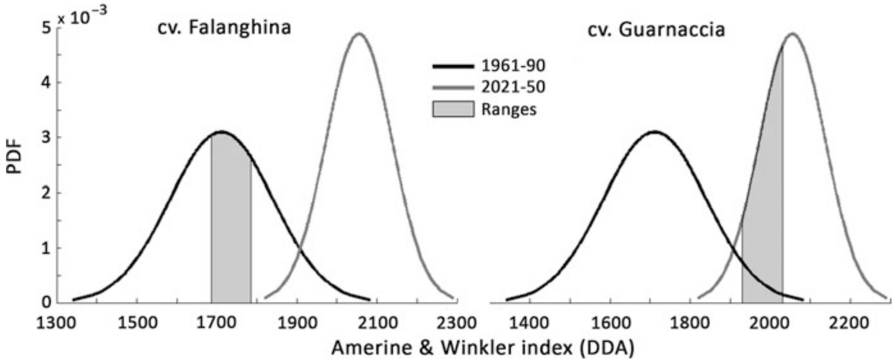

Fig. 8 Amerine and Winkler index distributions in the reference and future climate, compared with the thermal requirement of two cultivars (Falanghina, Guarnaccia); *shaded area* indicates the probability that either cultivar is compatible with reference and future climate conditions

An increase of the Amerine and Winkler index is foreseen under future climate conditions (Fig. 8): this increase reduces the adaptability of some cultivars (e.g., Falanghina, an important variety in the Campania region) and improves the adaptability of some others (e.g., Guarnaccia). A particularly significant consequence is the displacement within the Valle Telesina of areas optimally suited for a specific cultivar. This does not appear when using statistics derived for a single location with the gridded climate data. Therefore, the spatial distribution of air temperature and of the Amerine and Winkler index was estimated and the assessment of adaptability repeated. The spatial distribution of adaptability based on the spatial distribution of the index (Fig. 9) shows that there will still be areas suitable to grow the Falanghina, although such areas will cover a significantly smaller fraction of the Valle Telesina and will be located at higher elevation. On the other hand, the area suitable to grow new varieties, such as the Guarnaccia, will expand very significantly (Fig. 9).

Olive. Water availability during the summer was evaluated using the *hydrologic indicators* calculated with the SWAP model for the reference and future climate cases.

Soil information was derived from an existing soil map at 1:50,000 scale (Terribile et al. 1996). The area includes 47 soil mapping units (SMUs) and about 60 soil typological units (STUs). The available water capacity (AWC, Fig. 10) calculated to 100 cm soil depth is lower in the SMUs located at high elevation because of the smaller soil depth (around 40–60 cm).

Daily values of the hydrologic indicators RSWD and RETD were calculated for each STU and for each year in the reference (1961–1990) and future climate (2021–2050) and then averaged over the period of time applied to the estimated hydrologic requirements. According to the available experimental data set, RETD values were averaged over the whole year, whereas RSWD values were averaged over shorter periods (namely, over the months when irrigation was applied).

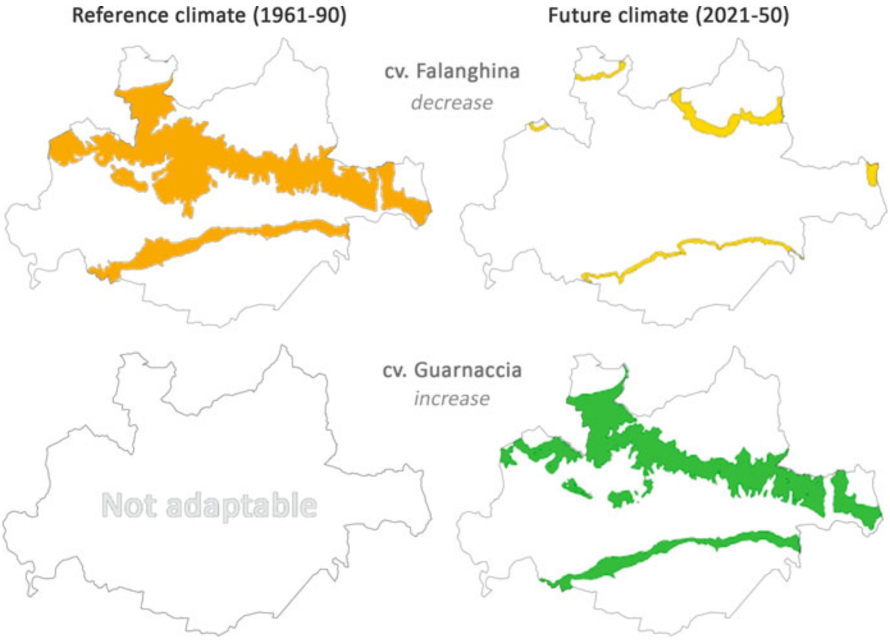

Fig. 9 Maps of areas suitable for the Falanghina (*top*) and Guarnaccia (*bottom*) grapevine varieties under the reference (*left*) and future (*right*) climate cases

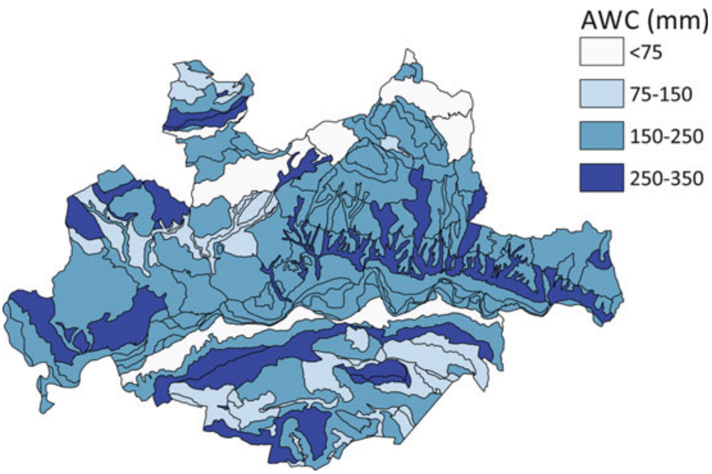

Fig. 10 Available soil water capacity (AWC) in 47 soil mapping units of Valle Telesina

Table 9 Cultivars' specific hydrologic requirements of relative soil water deficit ($RSWD_{cv}$) and relative evapotranspiration deficit ($RETD_{cv}$). Standard errors of requirements and determination coefficients of regressions are reported

Olive cultivar	Values	SE	R^2	Reference
	$RSWD_{cv}$			
Manzanilla fina	0.469	0.104	0.67	Correa-Tedesco et al. 2010
Leccino	0.619	0.028	0.84	Tognetti et al. 2004
Frantoio	0.659	0.048	0.69	Tognetti et al. 2004
Maiatica	0.673	0.022	0.93	d'Andria et al. 2008
Nocellara del Belice	0.695	0.045	0.75	Tognetti et al. 2004; d'Andria et al. 2008
Itrana	0.708	0.062	0.63	d' Andria et al. 2008
Ascolana tenera	0.712	0.037	0.84	d'Andria et al. 2008
Kalamata	0.726	0.062	0.67	Tognetti et al. 2004; d'Andria et al. 2008
	$RETD_{cv}$			
Arbequina	0.315	0.033	0.88	Iniesta et al. 2009
Cobrancosa	0.353	0.015	0.97	Fernandes-Silva et al. 2010
Picual	0.393	0.006	0.98	Moriana et al. 2003

In the study area, most olive groves are currently grown under rainfed conditions. The level of relative yield attained under these conditions was thus identified for each cultivar and indicated as the set point for adaptation (Yr_{adapt}), i.e., the yield level below which yield reduction is unacceptable.

A database of cultivars' *hydrologic requirements* ($RSWD_{cv}$ or $RETD_{cv}$) and their associated errors was set up (Table 9).

Adaptability assessment. For each cultivar, SMU and year the probability (P) of $RSWD_{soil}$ (or $RETD_{soil}$) being lower than $RSWD_{cv}$ (or $RETD_{cv}$) was calculated taking into account the error distribution. Subsequently, the median (M) of the P values for each climate period and SMU was calculated. These M values were pooled into a single distribution whose quartiles (Q) were determined and used to set adaptability ranges. The quartile Q1 had a rather low value (0.005) and very close to the minimum value (0.00) so the following ranges have been considered: from minimum value to Q2 (0.00–0.16), from Q2 to Q3 (0.16–0.67), and from Q3 to the maximum value (0.67–1.00).

The adaptability assessment for cultivars Itrana and Frantoio is shown in (Fig. 11). The adaptability in the future climate was lower than in the reference climate for both cultivars, since a higher soil water deficit occurred in the 2021–2050 period (data not shown). The medians M of the probabilities of adaptation were in the 0.67–1.00 (Q3 to maximum value) and 0.16–0.67 (Q2–Q3) ranges, respectively, for cv. Itrana and Frantoio in the major part of the valley in the reference climate (1961–1990). In the future climate, there was a shift of the median values toward the lower ranges: 0.16–0.67 for cv. Itrana and 0.00–0.16 for cv. Frantoio.

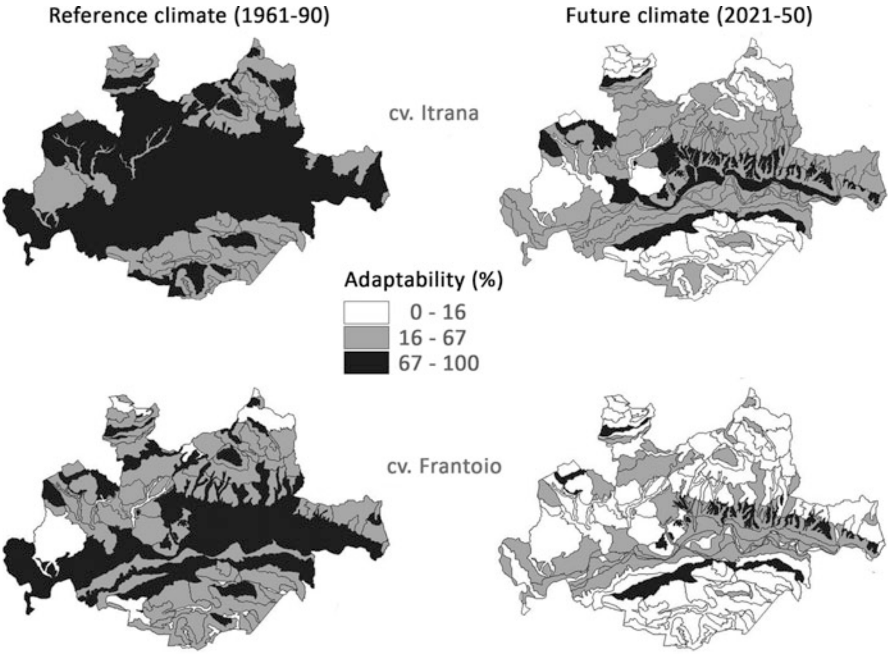

Fig. 11 Probability of adaptation of olive cv. Itrana and Frantoio in the reference (1961–1990) and future (2021–2050) climate in the 47 soil mapping units of the Telesina Valley considering the quartile ranges determined

Table 10 Percentage of the study area where cultivars are adapted with probability > Q3 in the reference (1961–1990) and future climate (2021–2050)

	Percentage of total area > Q3	
Cultivar	1961–1990	2021–2050
Manzanilla	0	0
Leccino	21	4
Frantoio	40	6
Maiatica	53	9
Nocellara	58	13
Itrana	66	14
Ascolana	62	19
Kalamata	68	19
Arbequina	0	0
Cobrancosa	12	0
Picual	44	37

In the reference climate, cv. Kalamata, Itrana, Ascolana, Nocellara, Maiatica, and Picual were adaptable in most of the area above Q3 (Table 10); this means that, for these cultivars, the median M of the probabilities of adaptation was higher than 0.67 in the major part of the valley. The other cv. showed a lower adaptability.

Case Study 2: Destra Sele

The study area "Destra Sele" (22,000 ha) is located in Southern Italy, in the Sele River plain (Campania Region, Province of Salerno). Destra Sele is characterized by five different geomorphic systems (dunes, hills/foothills, conoids, terraces, alluvial plains) with heterogeneous soil parent material that originated very different soil types: mollisols, alfisols, inceptisols, and entisols. The soil spatial variability is very high; thus, 23 STUs and 20 SMUs were identified. The irrigation scheme (15,000 ha) is managed by the consortium "Destra Sele," a state-controlled association of farmers. At present the available water resources fulfill farmers' water demand.

Maize and vegetables crops (tomato, fennel, cauliflower) are grown in the "Destra Sele" area. In this case study, we focused on processing tomato and maize. In the Province of Salerno, maize is grown on 2,450 ha, and the yearly grain production is 13,900 t (ISTAT 2012). Processing tomato is grown on 1,100 ha in the Salerno Province, and the yearly production amounts to 62,000 t (ISTAT 2012).

Vulnerability challenges. In Italy, both maize and tomato are among the crop with the most intensive use of agricultural land, with a high input of water and fertilizers. Maize is rather vulnerable to reduced water availability, and it is most sensitive (i.e., highest potential yield loss) to water stress during pollination, followed by grain-filling and vegetative growth stages. As regards tomato crop, a proper water management is a key factor to obtain high fruit yields. A prolonged water deficit limits growth and reduces yield; fluctuations in soil water content may induce physiological disorders. On the other hand, excess water may determine both reduction in fruit quality and yield and a negative environmental impact, such as nitrogen leaching.

Signature of climate change. Irrigation strategy determines whether and how the climate signal is observed. In a future (and warmer, as foreseen) climate scenario, if water availability would not be limited, the increase in crops' water demand could be fully met by irrigation, and the influence of a (moderately) warmer and drier climate on production could be offset by higher irrigation volumes. The climate signal would thus translate into higher water consumption.

In a more realistic future scenario, water availability will be limited and a suboptimal quantity of water will be delivered to crops, and the climate signal would translate into a soil water deficit. Under water shortage conditions, irrigations are scheduled according to the constraints of irrigation schemes: the signature of climate will thus depend on the matching between irrigation schedule and crop water requirements.

Moreover, intraspecific differences in crop water requirements and resistances to stress influence crop response to climate. Therefore, the interplay of water management strategies and cultivars' hydrologic requirements was explored.

Definition of irrigation strategies. Different irrigation scheduling options were defined and evaluated using the model SWAP, as described above. Schedules were designed for each climate case (1961–1990 and 2021–2050) and for each soil (23 STUs), from optimal irrigation to different levels of deficit irrigation.

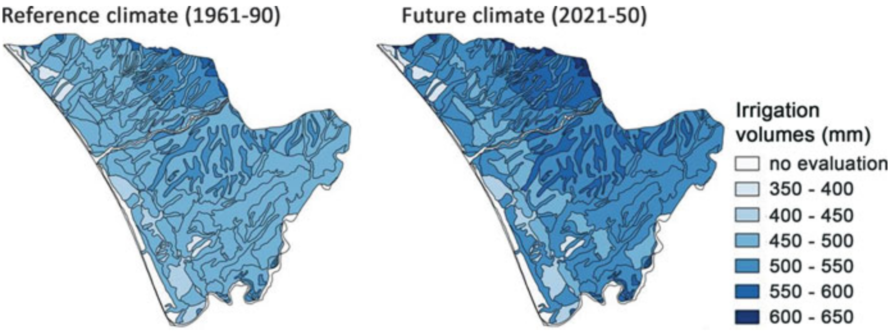

Fig. 12 Spatial patterns of seasonal irrigation volumes for a maize crop at optimal irrigation scheduling in the reference (1961–1990, *left*) and future (2021–2050, *right*) climate

Seasonal irrigation volumes were calculated in each STU, in the reference and future climate. For maize (Fig. 12), seasonal irrigation volumes, averaged over the 23 STU, increased by 8.8 % from reference to future climate for the optimal irrigation case. On average the largest differences in irrigation volumes were obtained in systems of hills/foothills and terraces and in the central portion of the alluvial plains. The increase was smaller for tomato: mean irrigation volumes increased by 2.7 % for the optimal irrigation case. The climate signal was thus different for the two crops. Irrigation volumes in maize and tomato varied due to their inherently different water requirements and to a small shift in their crop cycle, which interacted with the rainfall distribution.

Effectiveness of irrigation. The effectiveness of each irrigation schedule was calculated as the marginal increase of transpiration per unit of irrigation volume:

$$\mathrm{IP} = \Delta Tact/Ir = (Tact_{Ir} - Tact_{Ir\ 0})/Ir \tag{11}$$

where

IP is irrigation performance

$Tact_{Ir}$ (mm) is the seasonal crop actual transpiration for each irrigation case (i.e., 100 %, 80 %, 60 %, 40 %, and 20 %)

$Tact_{Ir\ 0}$ (mm) is the seasonal crop actual transpiration with no irrigation (0)

Ir (mm) is the seasonal irrigation volume applied for each irrigation case

In both climate cases, the irrigation performance was always higher for the maize crop. Optimal irrigation gave the lowest IP, which increased when reducing irrigation volumes up to 40 % of optimal irrigation. The tomato crop had a higher vulnerability to water shortage, with the maximum irrigation effectiveness at 60 %, with a noticeable decline at lower irrigation volumes.

Hydrologic indicators. Soil water availability was described by means of the hydrologic indicators $RSWD_{soil}$ and $RETD_{soil}$. Due to the definition of the irrigation strategies (i.e., optimal irrigation and proportional reduction of water depths in deficit irrigation schedules), the hydrologic indicators' values for each soil and for the same irrigation schedule were similar in the two climate cases (Fig. 13).

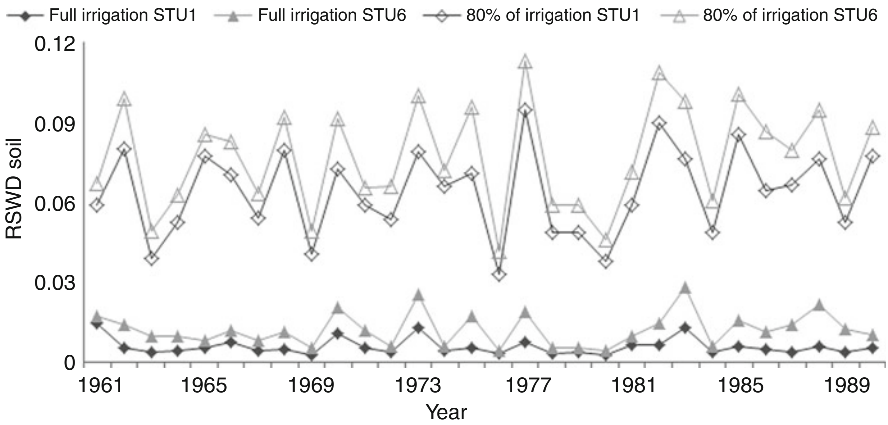

Fig. 13 Reference climate: hydrologic indicator $RSWD_{soil}$ in the maize crop, calculated for soil typological units (STUs) 1 and 6 at two irrigation levels (optimal irrigation and 80 % of optimal volume)

$RSWD_{soil}$ values are averages of daily data throughout the crop cycle. STU 6 showed a higher sensitivity to the reduction of irrigation volume. Within each soil, the interannual variability was significant, particularly at the 80 % irrigation level.

Hydrologic requirements were determined for five maize hybrids and four processing tomato cultivars (Table 11). Maize hybrids of FAO maturity class between 600 and 800 are commonly used in the study area.

Yield response functions of maize cultivars were represented by a linear regression model (Djaman et al. 2013). The yield set point for adaptation $Yr_{adapt} = 0.9$ was applied. The corresponding value of RETD was applied as the cultivar-specific hydrologic requirement ($RETD_{cv}$) (Fig. 5).

The available data set on tomato cultivars allowed to represent yield response functions to relative soil water deficit (RSWD) according to a threshold-slope regression model. The value of the indicator (RSWD) corresponding to the threshold of the response function was set as the cultivar-specific hydrologic requirement ($RSWD_{cv}$). An error of estimation, due to the empirical relationship between relative yield and water availability data, was associated to each $RSWD_{cv}$ (or $RETD_{cv}$).

In Table 11, values of $RSWD_{cv}$ and $RETD_{cv}$ span quite different ranges. Besides intraspecific differences in crop responses to water availability, this is due to the different phases of the crop cycle in which the requirements were determined.

Adaptability Assessment

Probability of adaptation. By comparing soils' indicators with cultivars' requirements, the adaptability was evaluated for all cultivars, soil mapping units, and climate cases, at irrigation levels 100 %, 80 %, and 60 %. The potential spatial distribution of maize hybrids and tomato cultivars was thus assessed in the study area.

Table 11 Cultivars' hydrologic requirements (and their standard errors) for maize and tomato crop

	Hydrologic requirement		Reference
Maize hybrids	$RETD_{cv}$	Stand. Err.	
Manuel (FAO 600)	0.16	0.01	Karam et al. 2003
NS640 (FAO 600)	0.17	0.04	Pejić et al. 2012
SandoxPX74 (FAO 700)	0.10	0.02	Istanbulluoglu et al. 2002
DelkabC5740RR (FAO 800)	0.07	0.02	Payero et al. 2006
Kaystar890 (FAO 800)	0.12	0.01	van Donk et al. 2013
Tomato cultivars	$RSWD_{cv}$	Stand. Err.	
Brigade	0.52	0.08	Patanè and Cosentino 2010 and unpublished data
Design	0.41	0.07	
Season	0.53	0.16	
Solerosso	0.54	0.13	

Table 12 Probability of adaptation: quartiles of the distributions of the medians

	Maize	Tomato
Q1	0.01	0.93
Q2	0.97	0.99
Q3	1	1

The ranges of the probability of adaptation were estimated for all cultivars (Table 12).

The second quartile (Q2) of each distribution was set as the lower limit for full adaptability. A cultivar was considered adaptable, therefore, when the median of its probabilities, in a soil and in a given climate case, was equal to or higher than Q2. In analyzing the probabilities of adaptation of tomato cultivars, the data values higher than Q2 were grouped, being the Q2 value (0.99) quite close to Q3 and to the maximum value.

As regards maize's probability distribution, the medians of a 25 % subset lay in a wide range of probabilities (i.e., $0.01 < P < 0.97$), from almost fully adaptable (medians close to Q2 = 0.97) to very low probabilities of adaptations (medians close to Q1 = 0.01). Another subset of medians showed probabilities of adaptation close to zero (i.e., lower than Q1).

Evaluation of cultivars' adaptation. At optimum soil water availability, all cultivars were adaptable (i.e., medians always higher than 0.97 and 0.99, for maize and tomato, respectively). However, in the future climate, the full adaptability could be maintained by increasing irrigation volumes, as discussed previously. Therefore, adaptability was assessed in a more realistic future scenario, i.e., at increasing scarcity of water resources. In both crops, adaptability resulted to be strongly dependent on soil hydrologic properties and cultivar biodiversity.

Figure 14 shows the spatial distribution of the adaptability of two maize hybrids (Manuel and Dekalb C5740RR) at 80 % irrigation level. Manuel resulted to be

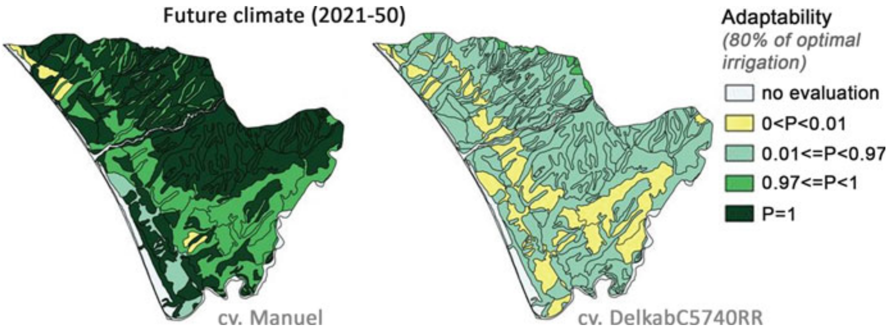

Fig. 14 Extent and distribution of adaptability of maize hybrids Manuel (*left*) and Dekalb C5740RR (*right*), at 80 % irrigation level in the future climate (2021–2050) in the soil mapping units of the "Destra Sele" area. The probability ranges are set according to quartiles

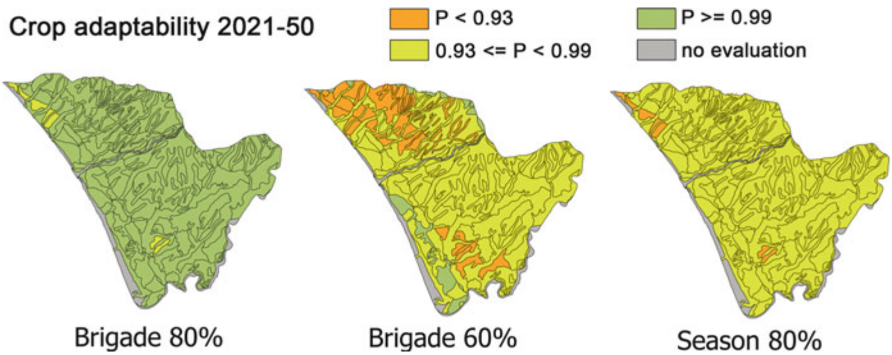

Fig. 15 Extent and distribution of adaptability of tomato cultivars Brigade (*left* and *center*) and Season (*right*) at 80 % and 60 % irrigation level in the future climate (2021–50) in the mapping units of the "Destra Sele" area. The probability ranges are set according to quartiles

adaptable (i.e., medians higher than 0.97) in 94 % of the total area and in some dunelike mapping units was not adaptable. The Dekalb hybrid, at 80 % irrigation level, was adaptable only in 8 % of the area. The choice among hybrids would therefore allow to sustain current crops' production at irrigation performances values higher than at optimal irrigation. At lower irrigation level (60 %), both hybrids were not adaptable (map not shown).

As regards tomato, the spatial distribution of adaptability for two cultivars (Brigade and Season) is shown in Fig. 15. The cultivar Brigade proved to be quite resistant to water shortages, being adaptable (i.e., medians higher than 0.99) at 80 % irrigation level, in 98 % of the area (Fig. 15, left); some dunelike areas, as with maize hybrids, were unsuitable. At the same water regime, cv. Season was adaptable with a lower probability (i.e., $0.93 \leq P < 0.99$) in the same area (Fig. 15, right).

With scarcer irrigation water (60 %), the probability of adaptation was $0.93 \leq P < 0.99$ in 83 % of the area for cv. Brigade (Fig. 15, center) and in 5 % of the area for cv. Season (map not shown). Due to the hydrologic requirements of the cv. Brigade, the highest irrigation performance (IP = 0.75) could thus be achieved, although at the expense of a decrease of the probability to attain optimal yield (0.93 vs. 0.99).

Case Study 3: Romagna

The *study area* is about 58,800 ha in the alluvial plain of Emilia-Romagna region (Italy), located within the cities of Lugo, Faenza, and Imola. Most of cultivated area is dedicated to fruit crop production (peach, apricot, pear, and kiwi).

Emilia-Romagna is the first region for peach (*Prunus persica* L.) cultivation in Italy. The crop represents more than 30 % of the regional agricultural area with 24,375 ha and 498,378 t of total production (ISTAT 2011). The subhumid climate of the area is particularly favorable for peach cultivation, while irrigation is a determinant for productivity since it improves the crop yield, fruit size, and quality (Battilani and Ventura 1996).

Vulnerability challenges. Fruit trees have different response to temperature and water availability depending on phenological development. The knowledge of peach cultivars' development cycle and timing and duration of phenological phases is important to define cultural practices, such as thinning, pruning, fertilization, phytosanitation, and irrigation and to identify the cultivars most adapted to a specific climate. Our objectives are:

– To describe the changes of phenological phases of several peach cultivars between reference and future climate by estimating timing and duration of phenological phases.
– To evaluate the consequent impact on the frequency of occurrence of extreme maximum and minimum temperatures that determines adverse effects on cultivars during specific phenological phases. This requires at first the characterization of thermal requirement for critical phases.

Thermal requirements. Time of phenological phases is regulated by the temperature range and by the cultivar response to temperature (Boonprakob et al. 1992). Cultivar-specific thermal requirements for each phenological phase were estimated by means of phase-specific thermal times using 3 years of phenological observations (2009–2011) on different cultivars (May Crest, Big Top, Stark Red Gold, and Royal Glory) within the "Romagna" study area. Thermal requirements were calculated by phase-specific models (Table 6) using meteorological observations at a ground station located at Imola. Baseline temperature for GDD calculation was set at 10 °C.

Table 13 Estimated changes (days) in the dates of peach phenological stages; positive values indicate later dates; negative values indicate earlier dates

Cultivars	Rest completion	First flowering	Full bloom	Fruit developed	Ripening
May Crest	6.7	−9.8	−10.1	−12.3	−12.4
Stark Red Gold	5.9	−9.2	−9.3	−14.8	−16.2
Big Top	6.1	−9.1	−9.9	−14.1	−15.6
Royal Glory	5.8	−9.1	−13.3	−14.6	−15.8

Two different requirements on critical temperature were considered:

1. High temperatures above which photosynthesis is reduced to a level that no appreciable growth occurs (Richardson et al. 1982).
2. Average temperature that determines 10 % bud kill after 30 min exposure was set to −2.7 during flowering and −2.5 during fruit development (Proebsting and Mills 1978).

Dates of occurrence of phenological phases. The dates of occurrence of each phenological stage were calculated in both reference and future climate using the cultivar- and phase-specific thermal requirements. The results (Table 13) indicated for future climate a delay in rest completion of about 6 days for all the cultivars. The flowering is anticipated by 9–10 days. Earlier ripening was also predicted, and the difference was larger for medium and late cultivars (respectively 15 and 16 days) than for early cultivar (12 days).

A Student's *t*-test was performed to evaluate the significance of the differences between the dates calculated for two climate cases (at the 5 % significance level) giving a good significance for all the phases and cultivars (except for Big Top ripening date).

Lopez and De Jong (2007) found that peach fruit size increased with the number of days between full bloom date and a reference date (defined as the date on which 80 % of sliced fruits have hardened pits near their distal end, plus 10 days). Thus peach was negatively affected during years with high spring temperatures since trees could not supply resources rapidly enough to support their maximum potential fruit growth rates. A shorter duration of phenological phases, therefore, can have consequence on fruit production even if, in our knowledge, current scientific research is still insufficient to give a quantitative description of the process in terms of thermal requirements.

Cultivars' adaptability to extreme temperatures. The frequency of crop-specific critical temperatures for each phase and cultivar has been calculated for reference and future climate taking into account predicted shift in timing and duration of phenological phases.

In the future climate case, the probability of occurrence of critical minimum temperature increases (Table 14) during flowering due to the effect of phase advancement, which exposes the crop to colder climate. Thus, the exposure to critical minimum temperatures is larger for earlier cultivars (May Crest).

The increase of mean temperature predicted for the future climate case increases the frequency of maximum critical temperature during fruit development and more significantly during ripening (Table 14). On the other hand, predicted earlier ripening reduces the impact of high critical temperatures (Fig. 16). High standard deviation suggests a large interannual variability of extreme events in the future climate case.

Conclusions and Perspectives

The work summarized in this chapter shows that the intraspecific biodiversity of agricultural crops has indeed the potential to offset the impact of climate variability and change without altering the current production systems. The assessments of adaptability of the production systems analyzed in the case studies (rainfed agriculture, irrigated herbaceous crops, and irrigated fruit crops) apply to the differences between a reference (1961–1990) and a future (2021–2050) climate case. For each crop evaluated, the adaptability of several alternate cultivars was assessed, although quantitative thermal and hydrologic requirements could be determined for relatively few cultivars in relation with the number of known and widely used cultivars for each crop. This is due to a generally insufficient documentation of climate conditions in literature on field trials of agricultural crops. To some extent, the inaccuracy of estimated thermal and hydrologic requirements is accounted for by the error of estimate and its distribution taken into account in the probabilistic assessment of adaptability as proposed and applied in the studies described in this chapter.

Climate stressors have different impacts on crop development, namely, extremely low and extremely high temperatures may halt crop development irrecoverably when occurring in specific phenological phases. Accordingly, adaptability should be evaluated by considering climate stressors in the sequence: (1) duration and dates of phenological phases, (2) mean temperature in specific phenological phases, (3) extreme temperature in specific phenological phases, and (4) water deficit.

The case study on rainfed agriculture did show that extensive substitution of olive and grapevine cultivars would be needed under predicted climate conditions. This would allow the preservation of the current production system but at the price of significant investments.

The case study on irrigated herbaceous crops did show how closely the choice of cultivars and the design of irrigation schedules are related. In addition to predict climate, changes in the available water resources should be estimated and irrigation strategies developed accordingly. Specifically, moderate deficit irrigation schedules and the choice of cultivars resistant to moderate water stress provide real options to adapt to scarcer water resources for irrigation.

The case study on fruit crops demonstrated that the dates of phenological stages must be evaluated first as a function of climate in order to assess the impact of

Table 14 Mean and standard deviation (in parenthesis) of the frequency of minimum and maximum critical temperature during flowering and fruit development for the reference and future climate cases

	1961–1990 (frequency • 1,000)						2021–2050 (frequency • 1,000)					
	Flowering		Fruit dvp		Ripening		Flowering		Fruit dvp		Ripening	
	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}
Royal Glory	0.0 (0.0)	–	0.0 (0.0)	0.7 (2.6)	–	0.0 (0.0)	0.3 (2.4)	–	0.0 (0.0)	16.9 (10.7)	–	66.5 (78.8)
Big Top	0.0 (0.0)	–	0.0 (0.0)	0.5 (1.8)	–	1.6 (8.4)	0.8 (5.6)	–	0.0 (0.0)	12.9 (9.3)	–	58.8 (54.4)
May Crest	0.0 (0.0)	–	0.0 (0.0)	0.0 (0.0)	–	0.0 (0.0)	1.9 (9.4)	–	0.0 (0.0)	1.9 (3.7)	–	25.8 (58.5)
Stark Red Gold	0.0 (0.0)	–	0.0 (0.0)	0.5 (1.7)	–	0.0 (0.0)	0.5 (3.4)	–	0.0 (0.0)	22.7 (12.3)	–	21.7 (54.9)

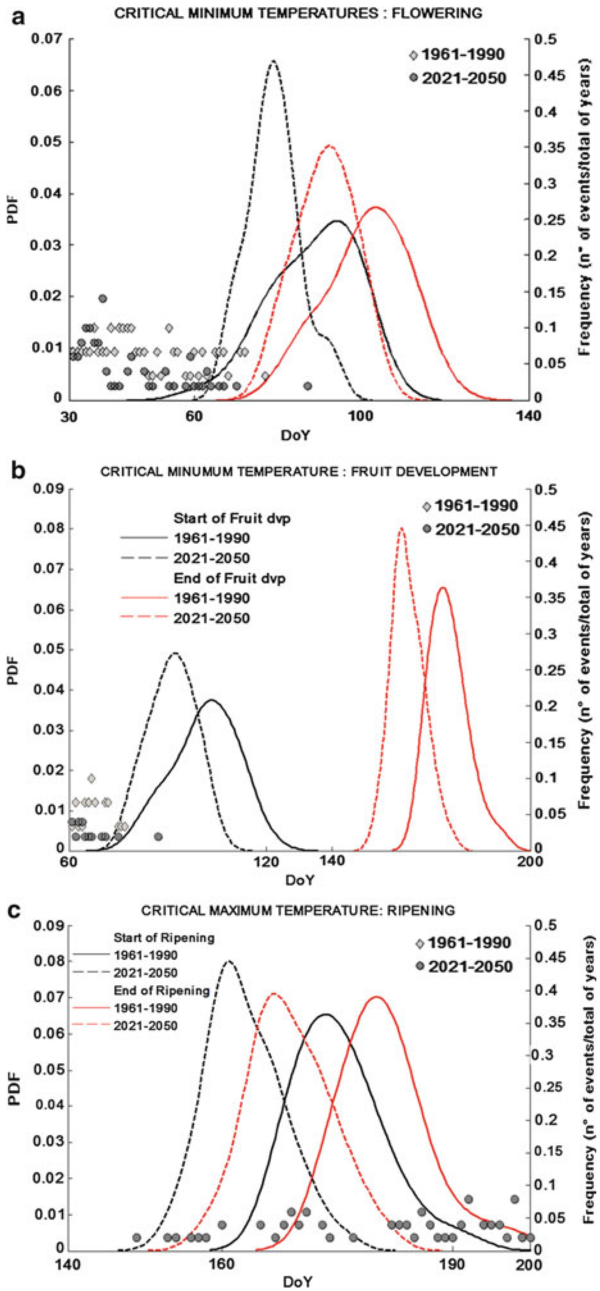

Fig. 16 Probability distribution functions of start and end dates of phenological phases (**a**) flowering, (**b**) fruit development, (**c**) ripening, in reference and future scenarios for May Crest cultivar compared to the daily frequency of the occurrence of critical temperature during each critical phenological phase

extreme temperatures and irrigation water use. Particularly, it was shown that interannual variability of phenological stages has a significant impact on irrigation water requirements.

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Glossary

Climate change Statistically significant variation either in the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer)

Climate variability Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events

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Adaptation Options to Improve Food Security in a Changing Climate in the Hindu Kush-Himalayan Region

Sarah Marie Nischalke

Contents

Abstract

This paper analyzes the food security situation in the Hindu Kush-Himalayan region (availability, access, utilization, and stability) and new challenges, emerging from climate and socioeconomic change. It addresses the challenge, particularly for policy makers, which of the various adaptations presented by science to choose and implement. All dimensions of food security will be affected by climate change impacts. Currently many different autonomous and

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planned adaptations are happening independently in the region and are not assessed or supported in a coordinated way. Prioritization is needed to effectively prepare the farm and food systems for changes to come.

The list of identified priorities contains, first, planned adaptations for short-term improvements in disaster preparedness (early warning systems, natural protection, and insurance schemes) and, second, adaptations that with a long-term perspective test and upscale options for local water storage and maintenance. The third priority is diversification of agriculture with a focus on localized climate- and nutrition-sensitive farming (crop diversity and climate-resistant crops with good nutritional performance). The fourth priority is to enable rainwater harvesting on household level through dissemination of knowledge on simple technologies and quality management. The fifth priority is to enable autonomous adaptation in the form of making better use of remittances and nonagricultural income sources to increase livelihood security.

Keywords
Hindu Kush-Himalaya • Mountain food security • Climate change • Adaptation options

Introduction

The Hindu Kush-Himalayan (HKH) region, which hosts one of the poorest and most vulnerable communities in the world, is highly dependent on agriculture and, of late, is facing major climate change as well as socioeconomic stress. All dimensions of food security, availability, access, utilization, and stability are affected. Mountain farmers from Yunnan (China), the Far West and Midwest in Nepal, to Assam in India report problems of low productivity and too much and too little water in an area that already is a topographically challenging terrain for agriculture. Farmers practicing predominantly rainfed agriculture struggle with the erratic climate, a late onset of monsoon, droughts, and flooding. Despite the condition of natural capital resources, migration leads to labor shortages and a restructuring of farming systems in the region. Cash crops of low labor intensity often serve as relief (tea in Assam, tobacco in Yunnan, fruit trees in Central Nepal) and move the system away from food self-sufficiency. Climate and sociocultural change also impact food prices, potentially deteriorating livelihoods and devaluating food entitlements because of an increased dependency on purchased foods (ICIMOD 2008). In addition, nutritional practices in mountains already have strong limitations, and nutritional environments often do not meet necessary requirements for nutritional security (Ebi et al. 2007).

The challenge, particularly for policy makers, is which of the various options and adaptations presented by science and practitioners to choose and implement. To improve food security, the choice should not fall between the different dimensions of food security but for the development of integrated strategies, for example, the promotion of climate- *and* nutrition-sensitive crops.

By reviewing recommendations for HKH, six categories of adaptation options were identified: (1) *Information management and research*: connecting scientific and local knowledge and recommending coordinated databases/research designs and new communication channels all to enhance knowledge management; (2) *Institutional and social innovation*: exploring options to respond to the increased complexity of systems through redefinition of social capital, farming and institutional flexibility, and new approaches in agricultural development and investment; (3) *Modification of agricultural practices*: suggesting usage of high-yielding varieties, tree crops, bioorganic farming, climate-resilient farming systems, and no-regret adaptation strategies to improve food security and strengthen resilience; (4) *Water resource management*: exploring different technologies of demand, supply, and quality management, including IWRM and rainwater harvesting; (5) *Financial security*: investigating adaptation potential of crop insurance scheme, microfinance, and migration; and (6) *Livelihood diversification and integrated approaches*: combining adaptation strategies with a focus on strengthening and diversifying livelihoods beyond agriculture.

There is no time to wait for perfect knowledge and a panacea does not exist but a need to act now and to prioritize. A prioritization can help the different HKH countries in strategizing adaptations for the mountains to improve food security. The analysis for this chapter is based on primary data, collected for the Himalayan Climate Change Adaptation Programme (HICAP), a collaboration among the institutions CICERO, ICIMOD, and UNEP GRID-Arendal. With the help of the Vulnerability and Adaptive Capacity Assessment (VACA) framework, developed in 2012, quantitative data was collected from five river basins in China, India, Nepal, and Pakistan (Upper and Eastern Brahmaputra, Koshi, and Upper Indus; data from Salween and Mekong basin is still under processing) to assess livelihood vulnerability and adaptive capacity and promote adaptation strategies to strengthen community resilience. This data was confronted by secondary literature on climate projections and adaptation options for HKH mountains in order to develop policy priorities in adaptation.

Scientific Gaps in the Analysis of Mountain Food Security and Adaptation

Though the literature on food security in the HKH region is vast and diverse, most of it has little relevance to mountain areas as it does not tackle the specificities of these *fringes of production* and provides little information on specific adaptation strategies tailored to these areas. This is due to the marginal role of mountains in national food security and negligible votes in these areas.

Digging through the plethora of literature on food security issues in the HKH countries makes one thing clear – there are three approaches to the topic of adaptation, which shelter a conflict in themselves: Do we prepare farmers for the unpredictable or do we prepare farmers for the predicted? Or do we improve agricultural techniques without putting emphasis on climate change, so that adaptation only is a positive side effect from technological progress? Adapting to the predictable assumes that strategies can be based on climate, crop simulation, and economic modeling. Estimates and research provide indicators for policy recommendations and planned adaptations mostly in the form of new technologies (Hussain and Mudasser 2007; Pandey et al. 2003; Kalra et al. 2007). The second camp bases its assumptions on uncertainty and the need to be well prepared for the unpredictable (Aase et al. 2010; Nadeem et al. 2012; Su et al. 2012). Instead of focusing on crop development, it means to strengthen capacities and flexibility, to extend knowledge and skills, to improve livelihoods, to increase diversity, and to reduce vulnerabilities, so that the strength to cope with stress and adapt to new circumstances increases. A comparative study in the Horn of Africa has shown that farmers with very limited capacities are not capable to adapt agricultural practices to new circumstances (Kristjanson et al. 2012). The third camp just deals with technical aspects of agricultural techniques, water availability, or productivity either without referring to climate change impacts or mentioning it in a subordinate clause only (Abrol 1999; Joshi et al. 2007; Quadir et al. 2007; Sharma 2009). One conflict pole was found in the fact that adaptation is highly complex and localized and needs locally adapted solutions, whereas for planned adaptation, a broad outreach and synergies, transferability, and upscaling are crucial.

Food Security Situation in HKH Mountains: Distinct from Food Insecurity in the Plains

For planning adaptation options, it is important to understand the root causes of food insecurity, their socioeconomic dimensions, as well as direct and indirect impacts of climate change on food production. Food security defined as “when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO 2009) is an acute problem in mountain areas. Half of the 58 most alarming countries in the Hunger Index have mountainous terrain (FAO 2012).

The challenges of ensuring food security are more daunting in mountains than plains due to limited arable lands, harsh climates, difficult terrain, and unfavorable biophysical conditions and because they are characterized by inaccessibility and fragility combined with political and social marginalization. In Nepal, for instance, food insecurity has become a concern in Mid- and Far-Western Hill and mountain districts. Food security has been a constant concern in other parts of the HKH region (Dame and Nuesser 2011). In many places, the average food self-sufficiency of rural HHs is between 3 and 6 months only. Besides limitations of arable land and land fragmentation, other reasons are declining, and stagnant agricultural productivity rates in predominantly rainfed agriculture and land use change at the cost of food production as well as a declining carrying capacity of the forests and rangelands (Nautiyal et al. 2007; Tulachan 2001). But also poor infrastructure and prices as well as deficient nutrition practices and seasonal disruptions in availability constrain food security. Further downstream, in the plains large populations are confronted by limited land resources and growing water stress, which provides more explanation why 51 % of the region's population is food-energy deficient (Rasul 2012). Around 150 million people in HKH mountains (Hunzai et al. 2011) are poor due to limited income-generation opportunities and exhibit high malnutrition rates.

The mountain farm households with small landholdings are increasingly exposed to economic, physical, and social risk and highly vulnerable to climate change and extreme weather events. Despite the challenging terrain for agriculture, farmer communities in the HKH mountains have established semi-subsistence farms that used to be well adapted to microclimates and make use of the ecosystem services that the Himalayas provide (crops, forest products, medicinal herbs, honey, etc.).

The HICAP research showed that more than half of the farming households do not even own 0.64 ha farmland that FAO (2010) estimates as necessary to enable a farmer to self-sufficient production, not to speak about setting up a social safety net or having an income source. Rural households without land are the most vulnerable to food insecurity; they usually lease land or use share-cropping arrangements. The diversity in crops and diets is low in most districts, and people consume on average the smallest number of food groups compared to the lowlands and urban areas. Even though the average quantity produced in cash crops (330 kg year) is low, it is perceived as a silver bullet to boost agricultural incomes that are threatened by environmental change. The farming systems used to be characterized as labor-intensive low-input systems. Now cash crop production fosters intensification. Chemical fertilizers replace soil fertility management, herbicides replace intercropping systems (Murray 2010), and diversification as a coping strategy of the region is gradually replaced by monocultures. Hence, these "new" systems need to be reevaluated under climate change conditions.

The farming systems are under immense stress due to shifting of flowering and ripening times and delayed sowing, and often replanting seeds is required to get a viable output. Because most of the agriculture in HKH is rainfed, water security is vital in order to achieve food security. Only 15 % of households in Eastern Brahmaputra basin (India) and 44 % in Koshi basin (Nepal) use irrigation, and many face severe water problems already. In Koshi water is sufficient only on an average of 4.6 months and in Eastern Brahmaputra for 3.2 months. Less availability of water for drinking, cattle, and agriculture requires adaptations.

Because people rely less on subsistence production, access to food has changed its face as well. In India, purchased food contributes to 46.8 %, and in Nepal 42.7 %; in Pakistan, food consumption in the mountain states contributes to 63.1 %; and almost 15 % would not be food secure without public distributions or food aid (see Table 1). Farmers depend less on environmental conditions and weather but become more vulnerable to market developments and prices as well as stability in labor markets and business revenues. Price hikes become a double-edged sword. While cash crop revenues increase, more has to be spent on food. While food prices go down for household consumption, also the cash crop revenues go down. Volatile global food prices result in higher real prices in the medium term.

Table 1 Percentage contribution of sources to household food consumption in the last 12 months HICAP PVA

Basin	Self-produced	Bought from store	Food aid NGO/IO	Food received from friends/ relatives	Food subsidies/ PDS	Shared crop on leased land	Others
Brahmaputra (India)	34.39	51.02	0.11	0.82	8.95	2.08	2.53
Koshi (Nepal)	53.67	44.20	0.23	0.68	0.14	0.9	0.18
Indus (Pakistan)	29.81	64.70	5.20	0.13	0.07	0	0
Total	**40.84**	**50.99**	**1.10**	**0.64**	**3.95**	**1.24**	**1.16**

In 2008/2009 this burden became visible, when the world saw a major food price crisis, where prices in South Asia and China skyrocketed and many farmers struggled to feed their families.

Maintaining a healthy nutritional status is extra challenging for mountainous populations. The growing seasons are short, the lean periods long. Plant growth is reduced due to cold temperatures, and only limited varieties of crops can grow on rough terrain. Nutritional security is threatened by monotonous diets, low dietary diversity (especially during winter), hard work, and compromised hygiene. The high work burden of women and lack of knowledge prevent good child feeding and caring practices, and existing gender roles and family hierarchies also lead to food deprivation of females (de Schutter 2012). The burden of disease from miserable hygiene and sanitation conditions and unsafe water is substantial. A large number of households use open pits as toilet facilities and open springs for drinking water. The steep slopes and harsh conditions reduce access to the often poor-quality health services. Stunting (height for age) as the indicator of chronic malnutrition is very high in mountains. In Nepal stunting prevalence in mountainous regions stands at 61.0 %, reaching up to 70 % in hot spots, as compared to the hills (46.4 %) and Terrai (43.5 %) (National Planning Commission 2013). In China stunting rates have been reduced to 9.4 %, but geographical variation is immense. In some mountainous states such as Guizhou or the district of Guangnan (Yunnan – 21.2 %), stunting rates cross 30 % (Zhao et al. 2013).

The most food insecure households are the ones with very little or no access to land and a high dependency on wage labor for income, a high dependency on rainfed agriculture and subsistence farming, and a small crop and income diversity. Many of them face severe water problems and labor shortages on their farms and are highly indebted. The resilience of farm households to shocks ranging from family sickness to price shocks, livestock disease, flooding, drought, or erratic rain is very low. Consequentially, the number of households with low capacity to cope with or adapt to climatic, environmental, or socioeconomic events is high. People lack knowledge and adequate responses and have no backup (food stocks, savings, insurance). These households have little capital and endowments that can be translated into food entitlements and find themselves in a situation of cumulative vulnerability: weak endowment structure, low income profile, frequent encounter with shocks, and land degradation or low productivity, which result in a very poor food and nutrition security situation.

Climates of Food Insecurity

The IPCC report projects rising temperatures, high rainfall variability, and increases in extreme weather events for Asia, which are likely to result in declining agricultural productivity, especially of cereals. Water and agriculture will be the most vulnerable sectors affected by climate change. Agriculture in HKH will be hit particularly by changes in water sources (Cruz et al. 2007). Douglas (2009) refers to peak flows in major rivers, which are likely to change, and food crops to be disrupted by variation in monsoon onset and duration and frequency of floods and droughts. Stresses will multiply due to urbanization and industrialization trends, which put pressure on resources, land use and cover, biodiversity, and human health. Crop yield decreases particularly for South Asia are projected at up to 30 %.

However, IPCC lacks data on assessments for the HKH mountain region because hydrometeorological information for historical time series is scarce and weather stations are too few. However, they are important parts of the earth's ecosystem, providing services not only to mountain communities but also to lowland populations (Beniston 2003). The Himalayas, also known as the third pole, have a crucial role in storing water through 50,000 glaciers, glacial lakes, and permafrost. HKH is one of the richest and most varied ecosystems, known for its variety in altitudinal vegetation belts with an abundant high biodiversity, but climate change effects are understudied. And food security depends on both availability of water and biodiversity. Rigorous research and policy advocacy are the needs of the day (Singh et al. 2011).

At first sight climate change adaptation in mountain areas suggests a strong focus on availability and market access as the natural capital resources here are the most dominant "currency" and livelihoods beyond subsistence widely depend on infrastructure and accessibility of marketplaces. There is no disaggregated data for mountains, but especially with regard to availability, yields of rainfed production of corn (40 %), rice (10 %), and wheat (5 %) are projected to decline (Singh et al. 2011). Livestock productivity is also likely to be affected by degrading animal health and declining milk yield.

Overall, the natural conditions for agriculture are projected to change. Cruz et al. (2007) point out that high temperatures enhance transpiration of plants and lead to increases in water demand and change soil texture. The evolution of weed species in warmer temperatures, vertical migration of species, reduction in winter kill of insects, and speeding up of pathogen growth rates (abetting diarrheal diseases and malnutrition) will pose further challenges to agricultural productivity and food security in mountains. It is not likely that negative effects can be outbalanced by longer growing seasons, improved timings of threshold events in crop development, or CO_2 fertilization. High temperatures also put pressure on transport and storage infrastructure, which is deficient in the region.

Decreasing agricultural output directly hit the rural poor, who depend on it for livelihood, while urban poor will suffer from future food inflation because they have to purchase food stocks. The new dependency on cash crops is likely to increase vulnerability to markets and prices in context of climate change (ICIMOD 2008), which will devaluate food entitlements if livelihood security deteriorates. At the same time nutrition is endangered to worsen through destroyed crops, livestock, and other livelihoods. However, new agricultural opportunities in the form of higher crop and diet diversity could also have positive effects on nutrition. All in all, it is expected that the health environments will change: with increased incidents of flooding or water scarcity because the risk of water-related diseases rises (Adshead et al. 2010; Ebi et al. 2007) and can adversely affect nutritional absorption. Therefore, an eye should be kept on impacts of climate change on nutrition practices (diversity) and sanitation as well as potential related adaptation options in the mountains. Competition for resources and land might add further pressures because people from flood-affected and arid areas are likely to move to the hills and mountains (e.g., in Bangladesh the Chittagong Hill Tracts) (Singh et al. 2011).

Socioeconomic Change in Mountain Communities and Implications on Food Security

Farm households in HKH face transformation in social structure that also affects the farming system's structure. An increasing dependency on purchased food shows that households cannot or do not want to sustain their household requirements from own production anymore. Farmers allocate resources differently; invest less time, labor, and money in subsistence agriculture; and focus more on off-farm employment or business activities. Impacts of climate change (declining yields and water sources, food insecurity, etc.) are one reason, but farmers are also more aware of opportunities outside their location and abroad. Communication technologies such as mobiles, radio, the Internet, and television promise income opportunities and a different future, and reduced transport costs enable people to travel. One effect is that many people migrate.

Migration is not new to this region, but it currently happens to an unknown extent and to a rising number of destinations. It is becoming the number one adaptation measure, boosted by the economic upturn in urban centers, e.g., in the Gulf countries and Southeast Asia. 15 % of the 200 million laborers worldwide come from HKH countries and many of them from mountain regions (Banerjee et al. 2011). This was reflected in the HICAP data, which showed that off-farm employment has become a popular livelihood strategy (see Table 2). In 2010 households in India received remittances from abroad of 55 billion USD, 51 billion in China, 9.4 billion in Pakistan, and 3.5 billion in Nepal. Migration is a challenge, but as a source of social and financial remittances, it also provides benefits (ibid.). Not only does it help to fulfill basic needs (e.g., food), but it can also support people

Table 2 Households with employment outside the farm (in percent, female participation in brackets) HICAP PVA

Migration and off-farm employment	India (Eastern Brahmaputra)	Nepal (Koshi)	Pakistan (Upper Indus)
Migration for work (inside the country)	**11** (3)	**18** (6)	**21** (>1)
Migration for work (abroad)	**1** (>1)	**24** (1)	**4** (>1)
Off-farm employment (business) for at least 10 months/year, at least one family member	**26** (3)	**19** (8)	**37** (3)
Off-farm employment (salary) for at least 10 months/year, at least one family member	**24** (11)	**32** (8)	**54** (8)

to recover from disaster (reconstruct houses and rebuild livelihoods after floods), prepare for disaster (invest in irrigation in drought areas, boats in flood areas), and adapt to climate change (purchase drought-resistant seeds or technology). In HKH migration is a highly engendered process (up to 40 % of males absent) and leads to feminization of agriculture and the whole mountain economies. The drudgery on women increases and negatively affects agricultural outputs, time allocation for food preparation, and caring of children and livestock. Especially if migrants are in poorly paid employment, remittances do not compensate for the missing male workforce and the money is not sufficient to employ laborers – so people are at risk to be less food secure than before. In contrast, if remittance earnings are good and women become the de facto heads of households, they tend to take better decisions for child nutrition and spend more on education and health of children. But often enough then agriculture is abandoned. Nowadays agriculture is perceived as a "socially demeaning occupation" in the region, meant for the illiterate (Hoermann et al. 2010, p. 7). The shift from subsistence to market orientation and out of agriculture shows this change in values. Agriculture as it used to be is not viable anymore, and in many places it does not provide income to fulfill material needs and health and education requirements.

Adaptation Options to Improve Food Security in HKH

Nowhere else in the climate change discourse is the issue of adaptation more present than in food production and security. Here also a trend from single technological solutions toward structuring adaptation along the value chain from production to consumption can be seen (Douglas 2009; Jhoda 1996) to tackle institutional, structural, and economic weaknesses of the food system. One reason is that the need to develop innovative forms of production and distribution or storage has been recognized. Integrative approaches such as the food-water-energy nexus (Rasul 2012) are also recommended to address the high interdependence of food, water, and energy security. Even though climate change adaptation has not much been investigated through the gender lens, women's contribution in agriculture and as food managers is more and more recognized and investigated (Krishnaraj 2006; Rao 2006).

Table 3 Applied coping strategies by households in three river basins (in percent, in the last 10 years) HICAP PVA

Coping strategy	Eastern Brahmaputra (India)	Koshi (Nepal)	Upper Indus (Pakistan)
Given up planting certain types of crops (livestock)	15 (2)	16 (9)	22 (18)
Introduced new crop or livestock varieties	11	17	30
Changed grazing practices	>1	7	16
Changed farming practices, e.g., delayed sowing/harvesting	14	15	33
Taken on new off-farm activities/ migrated for work	23	15	20
Farmland was left fallow/farming abandoned	3	11	6
HH invested in irrigation (community investment)	6	7	2
Community invested in irrigation	4	3	9
HH invested in disaster preparedness	10	5	13
Community invested in disaster preparedness	3	1	9
Have done nothing	76	51	4

Farmers are struggling to maintain availability in food security in the context of climate change and environmental degradation. The perceived changes are also reflected in adaptations in the investigated river basins, where the research showed that coping practices are applied (see Table 3). Most common is the change in farming practices (21 %): delayed sowing (especially paddy) and harvesting but also resowing of crops such as maize, barley, buckwheat, or vegetables. Traditional staple crops such as paddy, maize, or wheat are given up (18 %), and livestock varieties such as cattle and goats are abandoned by 10 % of households. The percentage of adaptations in disaster preparedness and irrigation also shows that people mostly move forward individually. Communities expressed the need for systematic support to develop community strategies in water and disaster management. Because farmers lack knowledge and resources, a large number of households have not applied any strategies.

Adaptation, defined as "an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2001), is found in forms of very different sets of strategies in the literature on HKH to spread or transfer risk and improve food security. The adaptation approaches can be divided into holistic approaches that remain rather general and combine different adaptation strategies (integrated farming system approaches, farming flexibility, institutional innovation, etc.) and the specific ones that have been evaluated or piloted and often are described as complementary with other options to be effective (climate-resistant crop varieties, crop insurance and microfinance schemes, water storage and harvesting infrastructure). Many issues are already taken up by institutions such as the International Centre for Integrated Mountain Development (ICIMOD), but open questions for policy makers remain which to prioritize, how to identify and disseminate the best simple low-cost technologies, and how to reach the most vulnerable groups with low capital profiles. Six categories of adaptation options were identified, which will be introduced in the following:

1. Information and knowledge management
2. Institutional and social innovation
3. Modification of agricultural practices
4. Water resource management
5. Financial security (crop insurance schemes, microfinance, etc.)
6. Livelihood diversification and integrated approaches

Information and Knowledge Management

Participatory information management aims at capacity building of farmers and wants to train "climate managers" whose knowledge will be based on agroclimatic zones, climate models and simulation in the form of weather forecast, agro-advisory services, and the establishment of mini agro-met observatories (Pande and Akermann 2008). Information such as market developments and specific weather codes, which recommend farming practices based on conditions of droughts (drought code) or floods (flood code), can be communicated through these risk managers, crop-weather watch groups, or village knowledge centers (Swaminathan and Kesavan 2012).

In addition participatory management of resources (collective vegetable planting, breeding crop varieties with desirable properties of stress resistance, management of forests) and indigenous knowledge (bio-farming, water conservation, etc.) can establish climate-resilient farming systems. However, before information management can take off, knowledge management is required. As long as research is producing data that is of high uncertainty and not shared or coordinated, how can risk or climate managers be provided with adequate information? Coordinated research and databases are suggested. A cross-regional database on land use, demography, infrastructure, water resources, and best practices can improve risk assessment for disaster preparedness (Sharma and Sharma 2010). To improve adaptive capacity, disaster management capability of institutions and efficient communication systems and logistics are needed.

Coordinated research on early warning systems, refined flood and water level forecasting (GIS), and upgraded flood planning and vulnerability maps are required. Karki (2011) recommends a transboundary IWRM database for Pakistan and the region for long-term documentation and the assessment of climate change impacts and adaptation measures. Research and farmer's ground realities need to be linked through participation and information backed up by scientific knowledge to increase resilience and improve food security. Having databases is not sufficient; dissemination and access to the information need to be thought out in detail.

Institutional and Social Innovation

Institutional and social innovation is one response to the information and communication gap between policy makers, researchers, and farmers. The problem of the high uncertainty of data and predictions, the question of local applicability, and the low reliability of institutions trigger responses such as farming flexibility, redefined social capital, or institutional adaptation. Farming flexibility as a form of adaptation aims at identifying “uncommitted potentialities” in farming systems, using the example of Manang (Nepal) to expand spaces of opportunities and increase adaptive capacity (Aase et al. 2010). The critical question of this approach remains, who is going to or supposed to identify the many different localized potentialities? One form of flexibility can also be the use of new local social institutions (Chaudhary et al. 2012), where participatory setups for agricultural and disaster management are used. Community-based biodiversity management (setting up home gardens, group funds) and participatory plant breeding and variety selection of stress-tolerant crops and livestock are at the center of this approach.

As precondition for effective adaptation, institutional flexibility is as much required as on community level (Bartlett et al. 2010). Many autonomous adaption options are available, but building and expanding basic infrastructure at local level will be indispensible such as expansion and refurbishing of irrigation or improvement of water storage infrastructure. Capacity building is needed on all levels to develop parallel strategies for autonomous adaptations and for drafting and implementing effective national adaptation plans. Also “alternative” paths need to be considered. In Chinese agriculture, where conventional approaches dominate, the lack of a redefinition of social capital is described as missed opportunity to enable coping with pressures of modernization; often much more conform to sustainable rural livelihoods. “Sharing local knowledge” could become a distinctive form of asset in addition to the other five capital forms (Shiro et al. 2007).

Modification of Agricultural Practices

The focus is put on investment in science and technology, and recommendations range from climate-friendly and biodiversity-based organic farming practices to the testing and dissemination of high-yielding varieties in the mountains. The investment into fruit tree species that are more resistant to climate stress is suggested as well as the establishment of sustainable agricultural systems and no-regret adaptations that are needed for sustainable development. Bhatt’s (2012) emphasis is put on diversified crop rotations, mixed cropping, integrated agroforestry systems with leguminous crops, and limited synthetic fertilizer usage. Local low water-demanding crops and animals suitable for the climate should be promoted and genetic material be preserved in local seed and grain banks. Other authors recommend high-yielding varieties for mountains (Hussain and Mudasser 2007) and targeted breeding, where genotype selection is based on weather extremes for autumn crops and erratic rain and temperature changes for spring crops (Mall et al. 2006).

Aggarwal et al. (2004) base their no-regret adaptations on augmenting production through biotechnology and increased income from innovative agricultural enterprises (value addition). However, the dissemination of high-yielding varieties brings about the risk of an increased amount of fertilizer, pesticides, and water and implies a high environmental risk. Generally, genotype selection and breeding should always be done in cooperation with the local communities. As tree species (Lu et al. 2012) can be more resistant to climate stress than field crops, improve soil fertility, and conserve water and nutrient cycles, planting trees (fruit, fodder, carbon), which is less labor and input intensive, could be one long-term solution for the restructuring of agriculture in HKH.

Water Resource Management

Water seems to become the issue for food security in mountains, where infrastructure maintenance and feasibility for the topography are most important factors. The main objective is storage of water through natural and artificial reservoirs. One option is to use existing infrastructure, e.g., reviving of dying springs (based on experiments from Sikkim, India). There micro springs, located in farm fields, were revived and used as source of piped water (through gravity flow), fed by groundwater, and recharged by rainwater and infiltration (Tambe et al. 2012). In order to "capture rain where it rains" (Pandey et al. 2003, p. 53), the development of microcatchments is necessary to make use of available runoff, aiming at extending storage periods (in the Global North harvested water is stored for up to 1,000 days). This includes the restoration of traditional village tanks, ponds, or earthen embankments that still exist, for example, in India, and are often not well maintained (sediments). Treatment of (polluted) rainwater, e.g., through solar filtration, might also be needed along with restoring decentralized facilities or recreating freshwater fisheries. Local cheap and farmer-oriented solutions to water scarcity also need to explore innovative technologies such as roof water harvesting for drinking, shallow aquifers using treadle pumps, fog collection, and micro-irrigation for cash crops (sprinkler, drip irrigation, or bubble irrigation as used in Pakistan). Farming practices need improvements such as soil moisture retention through traditional mulching or new plastic film technologies, and recharge areas of spring and groundwater require protection (restrictions for cattle, closed spring boxes) (Merz et al. 2003).

Sharma (2010) and Laghari et al. (2011) follow a broader integrated water resource management approach. Sharma supports an approach that combines simple indigenous structures with large sectoral or multipurpose reservoirs and watershed management. Simple low-cost options such as rainwater harvesting are an important priority to capture water for domestic use (rooftop storage). Watershed management is needed along with water-conservation techniques for rainwater harvesting and soil moisture storage, which can lead to increased soil infiltration, recharging groundwater. Laghari recommends aquifers for artificial groundwater recharge due to a good storage capacity and reservoir management to solve the problems of sedimentation. Waste water infrastructure and water pollution prevention strategies e.g., in form of legislation are required. In addition green approaches to farming are needed that improve water productivity, promote suitable crops to surface and groundwater and integrate livestock or fisheries to increase value per unit of water. The water issue, supply, demand, and quality management is complex and needs well-planned IWRM with a strong focus on rainwater harvesting and other locally tested low-cost options for the diverse areas in HKH. Policy needs to foster planned adaptation in order to solve issues of irrigation, storage, and maintenance and improve farming practices while meeting the high uncertainty.

Financial Security

Adaptation strategies of financial security that transfer or spread risk are still underexplored. Migration enhances the overall capacity of households to adapt to climate change and can positively influence resilience for those left behind through a reliable flow of remittances. Remittances can enable smooth consumption, positively influencing food security, and often bring back entrepreneurial and agricultural skills as well as nutritional knowledge (Barnett and Webber 2010). However, the loss of labor in agriculture can adversely affect food security, so that channeling of remittances and support in climate-smart investment decisions are needed.

Agrawala and Carraro (2010) show how channeled resources (microfinance) at subnational level in Bangladesh have responded to needs of disaster preparedness and the agricultural sector. Microfinance there is targeted at reducing vulnerability to weather and climate risks (water management, agriculture, fisheries, forestry, and health) and contributes to adaptation through supporting the accumulation and management of assets. Critical points remain that microfinance usually targets the economically active poor, has high monitoring and administrative costs, and is not suitable as a long-term solution. In microfinance flood risks and general management of hazards are absent and crop production risks neglected. The Climate Change Cell (2009) has investigated the potential of crop insurance products to strengthen financial security and spread risk in agriculture in Bangladesh (production of yield, price, and market asset). The weather index-based insurance scheme came out as the most affordable and accessible to rural poor and the most practical to implement. However, insurance remains a business and not an income opportunity. Problems to be solved are lack of reliable data on weather patterns, crop yields, and land record systems, lack of insurance consciousness and poverty of farmers, lack of trained personnel, and limited financial resources.

Livelihood Diversification and Integrated Approaches to Adaptation

Because often government services are not responsive to climate change threats, livelihood diversification is an important adaptation strategy, which addresses underlying causes for vulnerabilities and can spread risk within agriculture and outside. Macchi et al. (2011) show the need for knowledge on climate-adapted crops and multiple cropping, water harvesting structures, and livelihood diversification options. Because living conditions determine adaptive capacity, flexible income-generation strategies are needed along with resilient resource management institutions, enhancement of knowledge and skills, and social capital (Bhandari and Grant (2007) to cope with constraints of insufficient agricultural land, insufficient labor within families, and lack of access to ecological agricultural services.

An integrated approach to adaptation (Gurung and Bhandari 2009) needs to be localized. For Nepal tested recommendations included sustainable intensification, considering water management and integrated trainings on marketing and agricultural techniques, livestock health management, and new business models (community-based), including cooperatives and crop insurances. In water resource management especially the rehabilitation of infrastructure (e.g., irrigation canals) was important for growing HVPs. Tree planting (fodder, timber, fruit) through forest user groups and the SALT practice for multipurpose cropping proved to be successful as well. Agricultural livelihoods need to become more resilient, and opportunities in the form of new enterprises (selling milk, etc.) should be explored. Last, climate change needs to be mainstreamed across the institutional landscape, so that it enables the efficient implementation of adaptation activities.

Prioritizing Adaptation Solutions: Disaster Preparedness, Water, and Climate-Smart Livelihoods

The analysis of the food security situation in HKH and current trends in climate and agriculture strongly suggest certain priorities for adaptation. The communities already experiment, so do researchers and policy makers in a rather uncoordinated way. Ideally, adaptation is done in an anticipatory rather than responsive way. People should at least be prepared to respond and develop a kind of adaptive thinking. The social acceptability and socioeconomic affordability is one major concern as well as it being endogenous to society and contingent on ethics, knowledge, attitudes to risk, and culture (Adger et al. 2009). A two-pronged strategy is suggested, which supports technologies and actions through planned adaptation based on current trends and needs of communities and upgrades knowledge for autonomous adaptation, strengthening farmers' overall adaptive capacity and flexibility. It can be seen as a quantum jump to single out priorities for planning adaptation, jointly tackling different dimensions of food security. For policy makers in the HKH region, these should be:

Priority List for Policy Makers

I. Planned adaptations:
   1. Short-term improvements in disaster preparedness (early warning systems, natural protection, and insurance schemes)
   2. Adaptations that with a long-term perspective test and upscale options for local large-scale water storage and maintenance
   3. Diversification of agriculture with focus on localized climate- and nutrition-sensitive farming

II. Supporting autonomous adaptation (contributing to I.1-I.3):
   4. Enabling rainwater harvesting on HH level through dissemination of knowledge on simple technologies and quality management
   5. Enabling efficient investment of remittances and other income sources in order to increase livelihood security, including access to food and nutrition (social organization/investment)

The first priority, a planned adaptation, tackles stability of ecosystems and nutrition and health environments. The projections for extreme weather events, water scenarios, and the high exposure to disaster in many areas in HKH require, first of all, improved risk assessment and disaster management capability to minimize human death, disease, and losses. Therefore, vulnerable areas need to be identified and prioritized in planned adaptation (vulnerability, flood, and drought maps), flood forecasting needs to be improved, and early warning systems need to be tested and installed in disaster-prone areas. For flood- and drought-prone areas, insurance systems should be supported and monitored and communication systems (institutional and communities) improved.

The second priority is a planned adaption and focuses on availability and stability of food production. The projections and current experiences of reduced water sources, decreased reliability in precipitation, and competition for resources suggest an integrated water resource management strategy, where local water storage is of highest priority, aiming at testing and upscaling large-scale water storage solutions (reviving existing infrastructure, installing aquifers, etc.). Additionally, improved maintenance, increased water productivity (irrigation techniques, crops), and conservation (water sources) should be promoted on district level. The aim is to improve long-term water security for agriculture and other purposes.

The third priority is a planned adaptation option that addresses challenges for agriculture such as disaster, water stress, temperature stress, and intensification stress resulting in decreasing productivity and nutrition performance. It tackles the availability and utilization of food and implies a policy reorientation toward climate and nutrition performance of agriculture instead of a profitability-first approach. Livelihood options also need to be evaluated and promoted according to their performance under climate change stress (traditional field crops, cash crops, tree crops, medicinal herbs, livestock, etc.) and nutrition and resource intensity (work, inputs such as water, fertilizer, etc.) and not only based on market value. Because biodiversity is important to spread risk and increase resistance and nutrition security, agricultural policy should discourage the silver bullet philosophy of monoculture cash crop systems in mountains. The integration of local knowledge and innovative approaches of collective management will ensure higher effectiveness and affordability of strategies. More coordinated research, including the compilation of existing techniques, is needed to give recommendations on climate-smart agricultural solutions for mountains.

The fourth and fifth priorities support autonomous adaptations and provide an increase in flexibility and adaptive capacity, which will help to achieve priority one to three. On the household level, water scarcity can be reduced with the help of rainwater harvesting technologies. It requires the dissemination of knowledge on simple technologies along with quality management and the provision of access to credit and technology are needed. This priority touches upon all dimensions of food security at household level. The support of social organizations might be useful to initiate installation of water solutions on community level, e.g., during winter. Best practice examples are known from Nepal, where communities jointly invested in infrastructure.

The fifth priority aims at enabling autonomous adaptation in the form of making better use of remittances and nonfarm-based income sources in order to increase livelihood security, tackling the dimensions of access to food and better nutrition. Knowledge on investment options and credit facilities need to be provided to encourage people to set up innovative agricultural or nonagricultural enterprises. Education is needed on how to best fulfill nutritional needs with available assets, because higher incomes do not automatically ensure better nutritional practices. Especially women are in need of knowledge of where to invest in order to become more efficient food and risk managers under changing circumstances (disaster management, farm management, nutrition, etc.). If remittances are used for investments in climate-smart agriculture, disaster preparedness (insurance), or irrigation, it can create win-win situations because the farmer, the farming system, and the community might benefit. Also social organization (e.g., water or women self-help groups) can be encouraged to jointly invest in irrigation systems, crop insurances, etc. Appointed climate change managers or knowledge centers could also help in spreading information.

Overall, a parallel approach of information and knowledge management is needed to fill knowledge gaps on climate-resilient farming systems and mountain nutrition. Information management needs coordinated communication, reliable research results, and proactive governance, whereas knowledge management requires intensified and tested localized research with regard to crop varieties, farming practices, water management, or financial insurance schemes. The final destination should be autonomous learning and exchange and transferability in the form of planned adaptation.

Conclusion

The food security situation in the Hindu Kush-Himalayan region is serious, and climate and socioeconomic change pose new challenges to its four dimensions (availability, access, utilization, and stability). This chapter identified adaptation priorities and showed that no panacea exists and a flexible approach should be followed in farming, institutions, and science. Policy reorientation will only be brought forward by well-informed policy makers backed up by research, development, and community support. Only a mixed approach of promoting tested climate-smart technologies and strengthening capacities of farmers (in and outside of agriculture) seems promising in order to spread risk and prepare farmers for the unknown. Adaptation options need to be reevaluated for local circumstances before implementation, and increased flexibility and capacity of institutions and farmers can help mountain communities to handle uncertainty and to spread out as much as possible.

Much remains to be done in terms of mainstreaming adaptation to climate change within the national policy-making processes of the HKH countries. Policy makers need targeting, and, to facilitate this, scientific research must be translated into appropriate language, practices, and timescales. Combining planned adaptation and fostering autonomous strategies by making use of scientific and local knowledge can prevent a science-first approach as well as free falling into the unknown transformation state.

ICIMOD with the help of CGIAR (Research Program on Climate Change, Agriculture and Food Security) is piloting and developing a concept of climate-smart villages for the mountain areas. It could become a role model for knowledge exchange and strategy development and through that provide an experimental ground for planned adaptation but will need institutional support to out- and upscale climate smartness in livelihood systems to improve food and nutrition security in HKH.

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Adaptation Strategies Against Salinity-Induced Vulnerability in Coastal Bangladesh

Mustafa Saroar

Contents

Abstract

Both climatic and non-climatic factors' induced salinity in coastal plains has posed a formidable challenge for livelihood security of natural resource-dependent coastal population in Bangladesh. This chapter is aimed to identify the broad adaptation strategies that are more likely to be employed by coastal people against salinity to secure their livelihood.

This study heavily draws on quantitative inquiry. Field data and information were collected through a semi-structured questionnaire from 225 respondents selected randomly from salinity-affected three coastal villages located around swampy mangrove forests – *Sundarbans* in Bangladesh. For data analysis various statistical tools, especially multinomial logistic regression (M-Logit) model, were used.

Subsistence agriculture, fisheries, open water fishing, and extraction of both timber and non-timber forest products from *Sundarbans* have appeared as the dominant sources of livelihood which are seriously impacted by salinity

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intrusion. Against the impacts of salinity, respondents have adopted almost a dozen of specific strategies and a couple of more they might adopt in the future as well. However, broadly there are three strategies they might eventually employ. M-Logit models have predicted that whether respondents would prefer *crop agriculture and allied jobs* over *saline shrimp farming* or *intensification of resource extraction from Sundarbans* would be significantly determined (LR chi-square = 308.17, pseudo $R^2 = 0.86$, $p < .001$) by factors such as socio-demographic (education [$p = .001$], occupation [$p = .02$], NGO's membership [$p = .00$], power in local polity [$p = .03$]), economic (farm size [$p = .002$], disaster recovery period [$p = .00$]), adaptive behavioral (seasonal migration [$p = .00$], shrimp-harvest failure [$p = .05$]), and spatial/locational (attachment to the locality [$p = .049$], tidal inundation of cropland [$p = .005$], land suitability for cropping [$p = .08$]) aspects. In line with these findings, suggestions are provided.

The policy implication of the study is if measures were taken in line with findings, it would help the poor and marginalized coastal population to better adapt with the impacts of salinity on their natural resource-based livelihood.

Keywords

Adaptive capacity • Adaptation strategies • Coastal livelihood • Salinity intrusion • Bangladesh

Introduction

This chapter has twofold objective: firstly to identify the impacts of salinity intrusion on the livelihood security of natural resource-dependent communities living in the south-west part of Bangladesh and secondly, to identify the factors that influence the coastal inhabitants' adaptation preference against salinity intrusion to secure their livelihood. Presence of salinity in soil, subsoil water table, and surface water bodies is not a new phenomenon along the shoreline of Bangladesh coast. However, over the decade due to accelerated sea level rise and tidal influence, the area under saline zone has been expanding very rapidly. Accelerated sea level rise induced by climate change is no more a contested issue as it is already accepted as a reality in the National Adaptation Programme of Action (NAPA) of Bangladesh (GOB 2005). Even the Intergovernmental Panel on Climate Change (IPCC), the authoritative global body on climate research, in its various assessment reports has warned that Ganges-Brahmaputra-Meghna (GBM) delta in general and the coastal Bangladesh in particular would experience sea level rise (SLR)-induced various problems including salinity intrusion (IPCC 2001, 2007). Some of the models projected that Bangladesh might experience almost of one-meter SLR by the end of this century (World Bank 2000; Agrawala et al. 2003). Bangladesh is one the 22 coast-lying countries most susceptible to climate change-induced SLR (Nicholls 1995; Middleton 1999; Oppenheimer and Todorov 2006). Globally 170 million populations would be affected by SLR-induced events, including salinity intrusion. Almost 35 million of them would be from coastal Bangladesh alone. One-fifth of the country might go under saline water (Warrick et al. 1996). Drawing from the study of Ahmed and Alam (1998), World Bank (2000) has shown a projected [high-end scenario] SLR of 30 cm and 50 cm for the years 2030 and 2050 along the Bangladesh coast. For every year average rise is 1 cm. However, projected SLR of 14 cm, 32 cm, and 88 cm along the Bangladesh coast for the years 2030, 2050, and 2100, respectively, is shown in National Adaptation Programme of Action (NAPA) for Bangladesh (GOB 2005, 2009).

Therefore, climate change and SLR are considered to be the most pressing problem against which the people of Bangladesh in general and the coastal people in particular have to adapt in this century and beyond (GOB 2008). Adaptation involves some processes and actions in order to better cope with, manage, or adjust to some changing condition, stress, hazard, risk, or opportunity (Smithers and Smit 1997; Fankhauser et al. 1999; Smit and Pilifosova 2001; Brooks et al. 2005; Smit and Wandel 2006). In climate change context, IPCC conceptualizes adaptation as adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities (McCarthy et al. 2001). Adaptation can be reactive or anticipatory based on the timing of adaptive response. Anticipatory adaptation involves taking measures well before the occurrence of the actual event (Smith 1997; Wilbanks et al. 2007). Adaptation can be private or public depending on whether the private individual or government agency is making effort to adapt to it (Adger et al. 2005). However, private and public adaptations are not mutually exclusive but rather often mutually reinforcing. Government program for exposure minimization often encourages private adaptation (Mimura 1999; Nicholls et al. 1999).

Like the citizen of any coast lying nations, the people of the coastal Bangladesh have only three options to deal with the vulnerability of SLR-induced events including increased intrusion of saline water in soil, subsoil water table and in surface water bodies. These options are protection, accommodation, and retreat (Klein et al. 2001; Tol et al. 2008). Protection involves construction of hard structure to minimize the exposure to increased salinity (Mimura 1999; Nicholls et al. 1999). However, taking this kind of measure is often beyond the private means because coastal populations are mostly natural resource-dependent marginalized people. Accommodation involves decreasing sensitivity through enhancing adaptive capacity (Adger and Barnett 2009; Adger et al. 2009). People having accommodative attitude would try to overcome the salinity-induced threats on livelihood without permanently evacuating their usual place of living. The last option "retreat" or pulling back to a safer place is basically evacuation which might involve relocation to a new place often faraway from the original one. Experts already warned that for a land-scarce country like Bangladesh which may even loss one-third of her landmass due to SLR, retreat may not be a sustainable solution. They put higher emphasis on adaptation in situ, i.e., encouraging people to be accommodative with the SLR-induced events including salinity. Practical manifestation of accommodative behavior is the adaptive livelihood. For following adaptive livelihood, people need to have adequate information about the likely change of climatic parameters which may affect their livelihood (Perry 2007; Collins and Kapucu 2008; Leal Filho 2009). Similarly, they need to have physical, social, cultural, and other forms of capital, assets, and organization (Blaikie et al. 1994; Smith 1997; Kelly and Adger 2000; de Hann and Zoomers 2005; Adger 2006; Blennow and Persson 2009; Saroar and Routray 2010; Wolf et al. 2010). Then again their past behavior of adaptation against similar threat on livelihood also influences the future course of action as regards adoption of adaptive livelihood (Patt and Gwatta 2002; Grothmann and Patt 2005; Grothmann and Reusswig 2006).

Bangladesh despite being a coastal nation, information on factors that govern the people's choice of adaptive behavior against the SLR-induced event especially against the burgeoning threat of salinity intrusion is still a gray area of existing body of knowledge. Only scanty of research on identifying the changes in the hydrometeorological processes (Ali 1999, 2003; Islam et al. 1999; Singh et al. 2001; Karim and Mimura 2008; Vineis et al. 2011; Bhuiyan and Dutta 2012; Pethick and Oxford 2013), identifying the locations particularly at risk (Castro-Ortiz 1994; Huq et al. 1998; Ali 1999, 2003; Saroar and Routray 2010; Rahman et al. 2011; Brammer 2014; Kulatunga et al. 2014), and characterizing and quantifying the impacts is available (Nicholls et al. 1995; Agrawala et al. 2003; Faruque and Ali 2005; Hoq 2007; Alvi and Dendir 2011; Ahamed 2013). Although, some scholars, for instance, Cannon (2002), Ahmed (2005), Ali (2006), Hoq (2007), Alvi and Dendir (2011), Habiba et al. (2012), Penning-Rowsell (2013) and Alam and Rahman (2014), have investigated the various aspects of current copping strategy against current natural calamities and hazards, none of them quantitatively assessed the influence of various factors that govern the people's adaptation preference for ensuring livelihood security. These are the gray areas of existing body of knowledge which this research would like to address.

Sea Level Rise and Impacts of Salinity in Coastal Bangladesh: A Succinct Review

Bangladesh, a tropical low-lying country, is historically prone to various hydrometeorological disasters such as floods, cyclones, tidal surge, and salinity intrusion (Islam et al. 1999). Climate change-induced SLR is going to extend this list. Numerous studies already have indicated that apart from its own direct impacts, SLR may even give synergistic effect to amplify the devastating power of currently occurring disasters that ravage the country recurrently (Castro-Ortiz 1994; Nicholls et al.1995; Huq et al. 1998; Ali 1999, 2003; Ali Khan et al. 2000; World Bank 2000; Singh et al. 2001; Cannon 2002; GOB 2006, 2009). In fact, the geographic location and geomorphological condition of Bangladesh have made it one of the most vulnerable countries to SLR in general and salinity intrusion in particular. Bangladesh is located at the interface of two different environments. The Himalaya is in the north and the Bay of Bengal is in the south. The interface between freshwater and saline water had been stable due to downward flow of freshwater from the Himalaya. Due to lower flow of water from the upstream and the accelerated SLR accompanied by strong tidal influence, the saline zone has been moving landward (further inland) from the shoreline of the Bay of Bengal. Now almost one-third of Bangladesh is under tidal excursions (Ali 1999, 2003; Rahman et al. 2011; Brammer 2014; Kulatunga et al. 2014). The country has 19 coastal districts in three distinct coastal zones. These are western, central, and eastern coastal zones.

Given the projected scenarios of SLR, salinity intrusion is now considered to be the most important single factor that may severely affect the livelihood security of the coastal inhabitants. In fact, increased salinity would interact with other hazards such as coastal flooding/inundation and storm surges in the low-lying coastal areas of Bangladesh. Nicholls (1995) and Nicholls et al. (1995) have shown that a one-meter rise in sea level and a 15 % increase in precipitation would inundate 71 million people. The SLR may also result in drainage congestion and water logging in the delta during high flow periods in the three major river systems in Bangladesh. Such a massive scale inundation will have severe impacts on agriculture and forestry, food security, human health, transport and infrastructure, and settlement and housing. Thus Bangladesh is shown as rank 1 in terms of the number of population likely to be affected by climate change and SLR effects.

Salinity intrusion has appeared as one of the important direct effects of climate change-induced SLR and other extreme events. Anticipated SLR would produce salinity impacts in three fronts: surface water, groundwater, and soil (Huq et al. 1998). Increase in salinity intrusion and increase in soil salinity will have serious negative impacts on agriculture (Faruque and Ali 2005). Because already about one million hectares of arable land is affected by varying degrees of soil salinity (DOE 2007), more adverse impacts are projected for the coming decades by Paul and Roskaft (2013). The presently practiced rice varieties may not be able to withstand increased salinity (Ahmed 2005; Ali 2006; Ahamed 2013). This might have serious repercussion on future food security and livelihood as agriculture is and continues to be the most dominant occupation in coastal areas. Increased salinity might affect the forestry and horticulture as well. The IPCC Working Group II has indicated in their fourth assessment report that for a 1-m rise in sea level, the "Sundarbans" mangrove forest is likely to be lost. Similar assertion is made by Organisation for Economic Co-operation and Development [OECD] in its study done by Agrawala et al (2003) and World Bank (2000).

Likewise, increased salinity in tandem with storm surge will cause reduction in fish production – another important avenue of coastal livelihood (Choudhury et al. 2005). In fact, for the last 2 decades or so, both freshwater and brackish water aquaculture, particularly shrimp farming in the coastal areas, are becoming popular and considered to be a lucrative business. Increase in salinity and coastal surge may not only jeopardize this lucrative business but may even arrest this trend (CARE 2003; Afroz and Alam 2013). This will also have serious implication on coastal livelihood. Although SLR itself is a slow onset event, scientific evidences warned that with accelerated SLR, the surge (both wave and cyclonic) height would increase significantly much like the same way as frequency and intensity of cyclonic events would increase (Ali 2003; Kulatunga et al. 2014). This is alarming as evidenced by the recent two cyclonic events such as *Sidr* and *Aila* which took place in 2007 and 2009, respectively, that brought about one-third of the south-west coastal floodplain under salty water for about 2 years. The accumulation of salt layer above the topsoil made the soil unsuitable for most of the agricultural crop production and even for keeping as pastureland. Almost after 5 years, partial recovery of productively of soil has been reported in few pockets of areas that experienced higher rainfall in the recent 2 years.

Finally, it can be reasonably assumed that accelerated SLR along the Bangladesh coast is likely to enhance the risks of coastal flooding, salinity intrusion, storm surge, and even catastrophic cyclone (Ali Khan et al. 2000; Singh et al. 2001; Bhuiyan and Dutta 2012; Kulatunga et al. 2014). Each of these will have network of impacts on coastal topography, morphology, social, economic and physical infrastructures. These all ultimately will affect the livelihood avenues of coastal population (CARE 2003; Thomalla et al. 2005; Afroz and Alam 2013). But the question remains. Are these impacts such as flooding, salinity intrusion, and storm surge, etc. new phenomena to the people of coastal Bangladesh? Simple answer is – these are not new. To impacts of these will be felt new indeed. They may feel the character, frequency, and magnitude of flood/coastal inundation, storm surge and salinity intrusion quite differently than the usual flood, seasonal salinity intrusion with which they are accustomed to. The coastal peoples are experienced in coping with normal flooding. For years they know when the flood water will pass through their farmlands and settlements. They know the duration (often very short lived) and character of flooding, i.e., slow/rapid onset-pick-recede. As they know the behavior of such flooding, they prepare their activity rosters, cropping calendars, and lifestyles and cope with the flood. Much like the same way, they get used to with the periodic salinity intrusion caused by tidal influence. They even use that brackish/saline water to culture shrimp on a seasonal basis alongside normal crop agriculture (Afroz and Alam 2013).

However, in the event of SLR, the inundation by salt water would be perpetual; it will increase over time and never get recede. Lowlands, farmlands, and even settlements and other physical and social infrastructures may gradually be abandoned over time. Likewise, salinity intrusion may permanently settle over farmlands, causing surface, subsurface water, and even soil completely saline. Such permanent salinity will not only seriously impede the agricultural productivity but also will damage the housing and other physical infrastructures. Further, crisis for freshwater for drinking will also be felt over time. Arguably one might say people will adapt in the future much like the same way as their ancestors did in the past. However, one needs to be mindful that adaptation does not take place automatically; certain factors govern the people's preference for adaptive response toward livelihood security (Scoones 1998; Adger et al. 2003; de Hann and Zoomers 2005; Pelling and High 2005). This study examines the influence of various factors on people's adaptation preference in coastal Bangladesh against the impacts of SLR in general and the salinity intrusion in particular.

Materials and Methods

Selection of Study Area, Respondents, and Survey Procedures

The whole coastline of Bangladesh are susceptible to multiplicity of disasters, and recent empirical evidence and scientific studies have warned that people of the south-west part of coastal Bangladesh are more vulnerable to various hydrometeorological disasters including cyclones, storm surges, salinity intrusion, and tidal floods (Castro-Ortiz 1994; Huq et al. 1996; Ali and Chowdhury 1997; Ali Khan et al. 2000; World Bank 2000; Singh et al. 2001; Karim ad Mimura 2008; Brammer 2014). This vulnerability may even increase in the changing context of climate; especially the accelerated SLR might amplify the devastating effects of many of these already occurring disasters. Dacope Upazila (subdistrict) of coast-lying Khulna District which is flanked in the south by the swampy mangrove forest (global heritage *Sundarbans*) and the Bay of Bengal was selected for empirical study (Fig 1). As the study site, two villages of Sutarkhali Union Parishad (lowest tier of local government unit in Bangladesh) were selected. The whole study area is separated from the mangrove swamp Sundarbans by Vodra River. Numerous other small rivers, canals, creeks, and brooks are in the study area which are important source of livelihood. The typical hydrological characteristic of this area is most part of lowland go under tidal water during high tides; therefore, two times each day many areas go under tidal flooding and such flooding by saline water takes severe form in the cyclonic period. Especially onrush of cyclonic surges often brings huge quantity of salt water from the Bay of Bengal and often the water get trapped and a thick layer of salt almost permanently settles over the land which seriously undermine the productivity of soil for cultivation.

As a survey instrument, mostly a semi-structured questionnaire was used to collect data and information. A total of 235 respondents were selected randomly for taking interview from where 225 responses were considered valid and used for this research. The survey was conducted during March to June in 2011. Interviews were done through administering Bengali version of semi-structured questionnaires. Three focused group discussions were conducted; these are male group, female group, and mixed group. Each group comprised of 10–12 members.

Result and Discussion

Climatic Disasters and Intrusion of Salinity

The entire area is historically prone to multiple natural hazards such as coastal flooding, cyclones, storm surges, salinity intrusion, and prolong/torrential rainfall. Apart from these, acute scarcity of freshwater for irrigation and drinking during dry season due to salinity intrusion is a major hazard. Although there are differences in the process of formation, timing of onset, duration of events, and even in devastating powers among these hazards, each has the ability to cause unprecedented

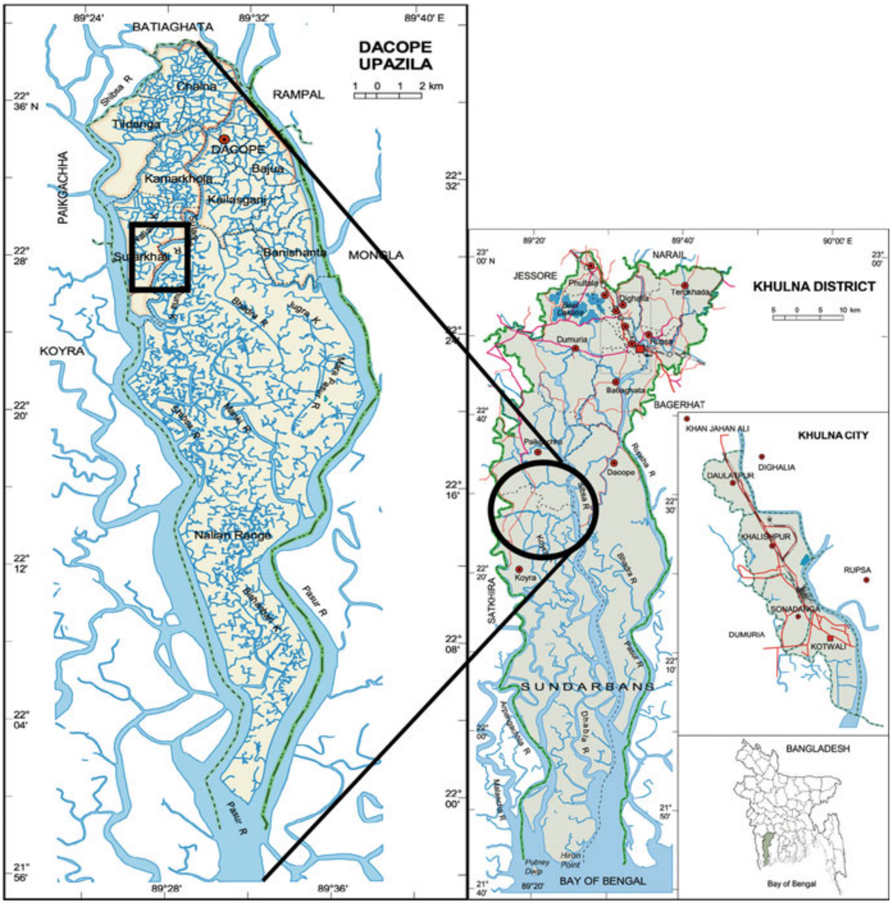

Fig. 1 The study site Sutarkhali Union (inside rectangle) in context of Dacope Upazila (inside circle) and Khulna District

damage to wealth, property, and other kinds of human well-being. In fact, ultimate impacts are felt on livelihood security. Although a very diverse portfolio of occupational engagement is observed in the study area and most peoples heavily depend on natural resource-based livelihood, some occupational groups are more affected than the others. Focused group discussion and other informal conversation with the respondents unveil that impacts of cyclone and surge are very universal. Direct impacts of cyclone and surge are felt by the respondents irrespective of their occupational engagement. The study area is located in the cyclonic path. The respondents have experienced several devastating cyclonic hits in their lifetime. Most recent of such events are category 4 cyclones – *Aila* and *Sidr*. The cyclone *Sidr* hit in the month of May 2007 and *Aila* struck in November 2009. Although the death tolls were not so high due to numerous reasons including good preparedness, the damages of property, assets, and livelihood avenues were unprecedented.

The entire area turned into a death valley. Thousands of homesteads were simply washed out; thousands of hectares of cultivable lands were underwater for many months as the trapped water could not pass away due to drainage congestion. People took refuge in uplands, embankments, and along the highways. They had to depend on outside assistance even for two meals a day for a year or so. The agricultural field, the fishponds, and shrimp *gheers* could not be utilized for the next 3 years as the salt layer was too thick on the bed of ponds, *gheers*, or in the cropland.

Unlike cyclone and storm surge, the impacts of salinity intrusion-induced freshwater crisis are not equally felt by different occupation groups in the study area. Impacts of freshwater crisis due to high salinity in water are more felt by people engaged in agricultural and other on-farm activities. These impacts are rather less felt by people engaged in nonagricultural activities such as small business, petty trade, and transportation.

Salinity Intrusion: A Dominant Cause of Threatened Livelihood

The coastal region as a whole and the study area in particular are in shortage of freshwater for crop cultivation (irrigation), fodder production, fish culture, and human consumption and similar domestic uses. It is primarily because the entire study area experiences severe crisis of fresh (non-saline) water throughout the winter season due to salinity buildup. Salinity in soil and water starts to build up after the month of October and reach in its peak in the month of April. Acute salinity in subsurface water table and in soil seriously impedes the cultivation of most winter crops including winter-season rice. Most parcels of farmlands are kept fallow throughout this winter due either to lack of freshwater irrigation or presence of extreme salinity in soil and water table. In other parts of the country hand tube well/shallow tube well with a maximum depth of 50–100 m is enough to ensure year-round sufficient supply of fresh (non-saline) water; in the study area, however, this depth range from 200 to 300 m entails higher cost. Moreover, the presence of hard rock layer in that depth makes it difficult to draw freshwater. The reasons of the presence of saline water throughout the subsurface water column could be attributed to lateral movement of seawater in addition to infiltration of saline water from surface sources. During high tide, saline water that accumulates in the surface water bodies, such as natural depressions, creeks, brooks, and canals is trapped and conserved by influential peoples to use in their saline water shrimp farms. Furthermore, few syndicates of influential shrimp farm owners are responsible for on-purpose ingression of salt water in the locality throughout the year, which severely affects the crop agriculture, horticulture, vegetable production, freshwater fish culture, and even production of animal fodders.

While conducting household survey through questionnaire, the respondents were asked to identify the major impacts of salinity on various aspects of their livelihood security. Almost 60 % of respondents face severe shortage of freshwater for drinking. Similarly 55 % of the respondents encounter difficulty in finding freshwater for irrigation. Lower yield in rice production is experienced by more than 50 % of respondents due to higher salinity in soil and water. Other impacts that the respondents feel due to higher salinity are presented in Tables 1 and 2. From the

Table 1 Impacts of salinity on livelihood of coastal population

The 10 most important impacts of salinity intrusion that negatively affects livelihood	Count[a]	Percent of responses	Percent of cases[a]
(i) Severe shortage of freshwater for drinking	133	12.1	59.9
(ii) Freshwater crisis for irrigation	124	11.3	55.9
(iii) Lower yield in rice production	115	10.5	51.8
(iv) Difficult to produce winter vegetable	107	9.7	48.2
(v) Reduced labor demand in dry season	103	9.4	46.4
(vi) Cannot grow most fruits	94	8.5	42.3
(vii) Shortage of fodder as no pastureland	89	8.1	40.1
(viii) Damage of building materials	85	7.7	38.3
(ix) Low catch in open water bodies	75	6.8	33.8
(x) Increased workload of women fetch water	71	6.5	32.0
(xi) Diarrhea and skin diseases	64	5.8	28.8
(xii) Cannot use paddy residuals for roofing	40	3.6	18.0
Total responses	1,100	100.0	495.5

[a]Multiple responses ($N = 222$; three cases are missing)

Table 2 Livelihood activities/inputs impacted by salinity in the study area

Assets and activities	Impact of salinity buildup and water stress condition
Aman (wet-season) rice	Increasing level of salinity and water stress condition affects growing to flowering stage of *Aman* rice
Boro (winter) rice	Acute high salinity restricts planting of *Boro* rice
Summer-season vegetables	High salinity affects planting of most summer vegetables during April to May
Winter-season vegetables	High salinity affects planting and growth of most winter vegetables during November to February
Culture fisheries/shrimp *gheer*	Although salinity has little impact, water stress condition affects productivity
Fish catch/fishing	Water stress condition and increase level of salinity render lower yield in open water bodies
Collection of fuel wood	Illegal extraction of fuel wood from mangrove forest *Sundarbans* increased due to lack of availability of biomass/paddy residuals
Cattle/goat rearing	High salinity degrades the pastureland during dry season and creates shortage of fodder
Poultry/duck (swan) production	Nonavailability of natural food due to increased salinity which affects subsistence poultry/duck rearing
Wage labor	Due to higher salinity, no winter paddy (*Boro*) production demand for labor is the worst
Water for drinking and domestic uses	Freshwater crisis prevails round the year but it is acute due to salinity in dry winter
Housing/settlements	Salinity severely affects building materials used in plinth, floor, and roof
Public health and sanitation	Prevalence of waterborne diseases, i.e., skin infection, diarrhea due to use of high saline water

summary of the multiple responses, it is evident that on an average almost five impacts are felt by each family due to higher salinity in soil and water.

Appraisal of Future Threat of Salinity Intrusion on Livelihood Security

Threat appraisal is contingent on both external and internal factors. External factors include source of threat itself (stressor or perturbation), probability of occurrence of the event, and the magnitude of the threat. Internal factors include person's level of familiarity with the event, perception and belief about the possible occurrence of the event, and comprehension of the impact (fear) from such event (Leiserowitz 2006; Fussel 2007). Threat appraisal is not something which cannot be changed; it changes indeed over time based on new information. Threat appraisal often influences the adaptive behavior (Maddux and Rogers 1983; Grothmann and Patt 2005). However, for appraising current as well as future threats, having knowledge about the causes/sources of the threats is fundamental. Respondents were asked to identify the cause of the accelerated pace of intrusion of salinity. They identified five causes of increased salinity in soil and water (Table 3). On average each respondent has identified three causes of intrusion of salinity.

Considering the reality of future SLR, dynamic nature of salinity, and the changing local land use and landscape, the respondents were also asked to identify the future scenario of salinity problem. How the respondents appraise the future threats of salinity on their livelihood is shown in Table 4. Well above two-third (68 %) of respondents appraised that impacts may be severe. Almost one-fourth (23.6 %) of them appraised that the impacts may increase but would not be severe. Very small number (8.4 %) of the respondents does not think that impacts of salinity would increase further and could appraise future threat.

Adaptive Livelihood Against Accelerated Pace of Salinity Intrusion

The entire study area experiences severe crisis of fresh (non-saline) water throughout the winter season. In fact, after the month of October, salinity both in surface

Table 3 Key causes/sources of intrusion of salinity in the study area

Most important causes/sources of intrusion of salinity	Count[a]	Percent of responses	Percent of cases[a]
(i) On-purpose ingression of saline water for shrimp culture	178	24.6	80.2
(ii) Cyclonic surges push saline water overland	174	24.1	78.4
(iii) Storing of saline water in illegally occupied canals	154	21.3	69.4
(iv) Strong tidal influence	147	20.3	66.2
(v) Siltation in riverbed allows saline water to travel further inland during high tide	70	9.7	31.5
Total responses	723	100.0	325.7

[a]Multiple responses ($N = 222$; three cases are missing)

Table 4 Appraisal of threat of future sea level rise with current awareness

The respondents were asked to appraise the overall threat from accelerated level of salinity; their responses are as follows:		
	No. of responses	% of responses
(i) Impacts of salinity may not increase	19	8.4
(ii) Impacts may increase but would not be severe	53	23.6
(iii) Impacts may be severe	153	68.0
Total	225	100
Mean		1.4
Standard deviation		0.6
N		225

water bodies and subsurface water table increases tremendously. Higher level of salinity persists for 4–5 months. Only after the onset of rainy season/monsoon, the level of salinity starts to decline. Acute salinity in subsurface water table and in soil does not permit cultivation of most winter crops including winter-season (*Boro*) rice. Even the shortage of animal/cattle fodders is acute throughout the winter due to higher salinity in soil. During this period to earn a living, a significant proportion of peasant farmers used to go for fishing in nearby rivers and canals located in and around the Sundarbans and in the Bay of Bengal. Furthermore, a significant proportion of people used to enter mangrove forest *Sundarbans* to collect both timber and non-timber forest products, such as honey, wax, sea grasses, fish, crab, etc. Seasonal diversification of livelihood is getting popular among the respondents. Many families, most of which are NGO beneficiaries, switch to cultivation of winter beans, legumes, nuts, and roots. Basically, with the assistant of extension workers of NGOs and agricultural department, the small and peasant farmers have been trying to adapt with the salinity and water stress condition by switching to cereals and crops that demand low water and can tolerate moderate level of soil salinity (5–10 dS/m). For instance, as winter-season rice (*Boro*) production is difficult, many farmers have been trying to cultivate sunflower, beans, sesame seed, and watermelon. Furthermore, some of them have adopted aeroponics vegetable production in handing bases made of recycled small plastic drums, buckets, bottles, canes, etc. Although in most cases productivity is less than normal, the peoples are happy that this production meets their own consumption need. The respondents believe that if they could be supported with drought- and saline-tolerant rice varieties with other agricultural implements, they could effectively adapt to the salinity problem even in a changing climate.

After agriculture and related farm activities, fishing is one of the dominant sources of livelihood. In fact, a significant number of poor and marginalized families heavily depend on both inland and marine fishing for their livelihood. The small fishers catch fish round the year in the open water bodies, canals, and rivers in and around swampy mangrove forest *Sundarbans*. As most of the small and marginalized fishers work as fishing workers in commercial trawlers, their marine fish-catch-based livelihood depends on the mercy of relatively rich commercial fish merchants, especially during the dry winter. During winter, the commercial fish merchants employ manpower to catch marine fishes in the offshore and in the deep-sea areas of the Bay of Bengal. This activity allows many unemployed youth to earn their living throughout the dry winter since they cannot sell their labor in the crop agriculture, which is heavily impacted by the water stress condition and higher presence of salt in soil and water. In fact, as the levels of salinity are increasing and prospect for crop agriculture is diminishing during dry season (November to April), a growing proportion of poor and marginalized people are being forced to enter swampy mangrove forest *Sundarbans* to catch fish in the bay, rivers, and canals located in and around this mangrove swamp. It means the *Sundarbans* mangrove swamp is going to experience higher pressure in the years to come.

Although increased salinity is a problem in general, a handful of rich and influential farmers have been considering increased salinity as an opportunity. Over the last 2 decades or so, many rich farmers have switched to saline/brackish shrimp farming practice. The lowlands that go under saline water have comparative advantage for saline/brackish water shrimp cultivation. Although saline shrimp culture has tremendous revenue potential, good harvest is highly variable and uncertain because of the presence of higher risk of production failure (Afroz and Alam 2013). Production failure or harvest failure in shrimp farms is mostly associated with viral attacks, climatic variability such as temperature increase, and coastal flooding, tidal surges, and even prolonged dry condition. This kind of production risk is difficult to assume by small farmers. Only the rich farmers go for this venture. This saline shrimp farming has scale economy; the larger the farm size, the higher the return and also the lower the production cost. Small- and medium-sized farmers cannot go for this venture. Again these shrimp farms only require small number of labors as compared to crop agriculture in a similar size farm. Therefore, conversion of crop agricultural fields into saline water shrimp farms has negative impact on rural employment market. Despite various social and environmental bearings, a growing number of rich and large farm owners have been switching to saline/brackish water shrimp farming and this trend may continue (Paul and Roskaft 2013).

As regards severe shortage of salt free freshwater, the people have been adopting two types of measures. The first one is related to use of pond-sand filter (PSF) technology for removing basically physical impurities. The PSF is a package type slow sand filter unit developed to treat surface water, usually pond water for domestic water supply. Treated water from a PSF is usually bacteriologically safe or within tolerable limits. With direct supports from local NGOs, community people have installed PSF unit near the bank of pond where they preserve rainwater throughout the rainy season. During winter when freshwater is very scarce due to the presence of excessive amount of salt in tube well water, the water from this PSF is collected on a community-managed rationing system. The other method that they have started lately is the rainwater harvesting through installation of simple harvesting apparatus on the roofs of their dwelling units. Throughout the rainy season they collect rainwater and preserve it in plastic containers. For preserving

Table 5 Broad adaptive responses for livelihood security against accelerated intrusion of salinity

	No. of responses	% of responses
(i) Switch to or continue with saline shrimp culture	41	18.2
(ii) Intensify resource extraction from the *Sundarbans*	69	30.7
(iii) Continue with crop agriculture and allied jobs anyway	115	51.1
Total	225	100

water they use plastic drums that they used earlier for stocking fish while fishing in the bay or rivers in and around *Sundarbans*.

Given the reality of SLR, the increasing trend of salinity, and their own appraisal about the threat of salinity in their livelihood, the respondents were asked to identify their main adaptation pathways. Although there are more than a dozen of specific strategies/action areas, broadly three types of responses have emerged (Table 5). Nearly about half of (51.1 %) the respondents want to continue crop agriculture and allied farm jobs anyway for their livelihood. Despite knowing the limitations of continuing agriculture in the future, they want to be with it because for most of them it is the only skill that they have. They believe in general that acquiring a new skill to fit with the changing context probably would be difficult for them in this juncture of their lifecycle. Almost one-third (30.7 %) of the respondents cannot precisely determine what they would probably do to secure their livelihood. However, one thing they are expecting to do is intensification of resource extraction from swampy mangrove forest *Sundarbans* and from the nearby Bay of Bengal apart from temporary outmigration. Looking into their responses, it seems that they are guided by short-sighted views; they fail to take into account of the impacts of climate change and SLR on the availability of resource of the *Sundarbans* mangrove swamp in the years to come. It is important because various earlier studies, for instance, World Bank (2000) and OECD (Agrawala et al. 2003), have estimated that almost half of the *Sundarbans* mangrove swamp would be lost before the middle of this century due to increased salinity and accelerated SLR. However, many of these respondents have been diversifying their portfolio of earning from various sources. The remaining 18 % of respondents express their willingness to either switch or (if already started) continue saline water shrimp farming. In coastal areas, increased adoption of shrimp farming means increased incidence of unemployed labor (Paul and Roskaft 2013). On the other hand, climate change-induced SLR and increased salinity would lower the earning of people from *Sundarbans* mangrove swamp and the nearby Bay of Bengal. Therefore the poor and marginalized people would be affected by double exposures of shrinking employment opportunity in shrimp farm sector and shrinking income from mangrove swamp *Sundarbans* and its adjoining bay areas.

In the following sections, it is attempted to quantitatively assess the characteristics that are associated with the people willing to adopt various (three) broad strategies for adaptation against the impacts of salinity on their livelihood. These strategies are (a) continue crop agriculture and allied farm jobs anyway, (b) switch to or continue with saline shrimp farming, and (c) intensification of resource extraction from the *Sundarbans* and its adjoining bay area (Table 5). Characterization of these groups would help identify the driving factors that govern their adaptation preference against the impacts of SLR and salinity on their livelihood. This is done through multinomial logistic regression model (M-Logit) because the dependent variables are categorical and mutually exclusive and the independent variables are interval, categorical, and binary variables (Hair et al. 2006). Details of variable selection and model specification are presented in the section below.

Modeling the Adaptation Preference Against Salinity

The categorical dependent variable "adaptation preference" has three mutually exclusive options of response such as "continue crop agriculture and allied farm jobs anyway," "intensification of resource extraction from *Sundarbans* swamps," and "switch to or continue with saline shrimp farming" (Table 5). As the options of response do not reflect a very precise ordering, multinomial logistic regression (MLR) model is used rather than ordinal/ordered logistic regression (OLR). Here the reference category is "continue crop agriculture and allied farm jobs anyway," which is compared with the other two. The independent variable (predictor) list includes various asset holdings; socio-demographic, cultural, and organizational factors; access to informational resources; adaptive behavioral aspects; and spatial/location factors and exposure potential. These independent variables have been selected from reviews of pertinent literature which are shown in Table 6.

Before running the MLR model, bivariate correlation is performed, and due to strong collinearity ($r > 0.90$) "total land holding" and "yearly income" are not used in the M-Logit model. Similarly, cross-tabulation for each categorical/binary independent variable with the dependent variable broad adaptation preference is performed. The independent variables which have zero count/frequency or count/frequency less than five in any cell of cross-table (matrix) were excluded from the model to avoid "floating point overflow" problem – a systemic problem that renders the modeled output less dependable. Finally, after running the model, factors that significantly explain the variations in respondent's preference for "intensification of resource extraction from Sundarbans" and "switch to or continue with saline shrimp farming" over "continue crop agriculture and allied farm jobs anyway" are identified. These outputs are analyzed to identify various interventions to build resilient coastal community against accelerated pace of salinity intrusion.

Model Output I: Who will prefer saline shrimp culture over crop agriculture?

M-Logit model depicts that respondents' preference for "switch to or continue with saline shrimp farming" over "continue crop agriculture and allied farm jobs anyway" as a strategy for livelihood security against SLR and other factors that induce salinity is statistically significantly (LR chi-square = 308.17, pseudo $R^2 = 0.86$, $p < .001$) determined by many demographic, social-economic, adaptive behavioral, and locational factors (Table 7). Most dominant factors are educational attainment ($p = .001$), duration of living in that locality ($p = .049$), experience of (shrimp)

Table 6 List of independent variables used in M-Logit model

Variables in detail[a]	Variable	Coding
Age of respondent (year)	Age (year)	
Education of respondent (year of schooling)	Education (year school)	
Family size (no. of members)	Family size (no. mem)	
Catching fish from swampy Sundarbans areas	Duration of fishing (year)	
Recovery period of damage caused by a cyclone	Recovery period (year)	
Duration of living in that coastal locality	Duration of living (year)	
If experienced harvest failure of shrimp (d)	Loss from shrimp	If frequent, 1; otherwise, 0
If homestead is on *khas* (govt.) lowland (d)	Location of homestead	If yes, 1; otherwise, 0
If most close relatives live in the same locality (d)	Relatives stay nearby	If yes, 1; otherwise, 0
If wage laboring is the main occupation (d)	Main occupation	If labor, 1; otherwise, 0
If cropland goes under tidal water during high tide (d)	Land submerse by tide	If yes, 1; otherwise, 0
If avoid giving ransom to pirates in *Sundarbans* (d)	Avoiding ransom	If always, 1; otherwise, 0
If seasonally migrate to outside locality for earning (d)	Seasonal migration	If always, 1; otherwise, 0
If member of any social group or NGO (d)	Membership of NGO	If yes, 1; otherwise, 0
If experience frequent embankment failure (d)	Embankment failure	If yes, 1; otherwise, 0
If abandon land frequently for high salinity (d)	Abandoning land	If yes, 1; otherwise, 0
If only plant rice in the wet season (d)	Only wet-season rice	If yes, 1; otherwise, 0
If frequently adapt to acute scarcity of freshwater (d)	Freshwater scarcity	If yes, 1; otherwise, 0
If has good connection with local political clout (d)	Political connection	If yes, 1; otherwise, 0
If always follow radio bulletin for early warning (d)	Follow radio bulletin	If yes, 1; otherwise, 0
Farm types based on landholding	Farm landholding	Small
		Medium
		Large

[a](d) indicates that the variable is dummy/binary coded

harvest failure ($p = .05$), submersion of cropland due to high tide ($p = .005$), suitability of land for single cropping ($p = .08$), power in local polity ($p = .03$), and farm/landholding size ($p = .002$; $p = .004$). Other factors have very limited influence in this respect (Table 7: Model I).

Table 7 Multinomial logistic regression estimates the influence of factors that determine the respondents' likely preference for crop agriculture and allied jobs over other two alternatives for managing livelihood

	Model I			Model II		
	Comparing preference for "switch to or continue with saline shrimp farming" over "continue crop agriculture and allied farm jobs anyway"			Comparing preference for "intensification of resource extraction from *Sundarbans*" over "continue crop agriculture and allied farm jobs anyway"		
	B: Coefficient	Exp B (odds ratio)	Wald chi-square	B: Coefficient	Exp B (odds ratio)	Wald chi-square
Age (year)	.163	1.177	.008	.024	1.024	.210
Duration of fishing (year)	.088	1.092	2.378	.278	1.320***	14.619
Education (year school)	.652	1.919***	.711	−.036	.964	.076
Recovery period (year)	.093	1.098	10.393	−1.853	.157***	13.405
Family size (no. mem)	−.592	.553	.021	−.337	.714	1.168
Duration of living (year)	−.120	.887**	1.530	.009	1.009	.095
Loss from shrimp	3.067	21.480**	3.859	−.978	.376	1.951
Location of homestead	1.503	4.493	3.826	−.376	.686	.153
Relatives stay nearby	1.005	2.731	1.409	−1.702	.182*	3.556
Main occupation	3.586	36.081	.493	−2.324	.098**	5.757
Land submerse by tide	−3.374	.034***	1.683	−.835	.434	1.377
Avoiding ransom	−1.153	.316	8.058	−1.630	.196**	4.090
Seasonal migration	−.134	.875	.642	2.686	14.676***	13.007
Membership of NGO	−.889	.411	.006	2.791	16.299***	13.195
Embankment failure	−3.411	.033	.665	−.615	.541	.339
Abandoning land	−.859	.424	2.438	−.465	.628	.338
Only wet-season rice	−1.819	.162*	.557	.053	1.055	.006
Freshwater scarcity	−1.683	.186	3.069	−1.633	.195	1.803
Political connection	−2.857	.057**	1.303	−1.866	.155**	4.175
Follow radio bulletin	−1.376	.253	4.759	−.771	.463	1.470

(*continued*)

Table 7 (continued)

	Model I			Model II		
	Comparing preference for "switch to or continue with saline shrimp farming" over "continue crop agriculture and allied farm jobs anyway"			Comparing preference for "intensification of resource extraction from *Sundarbans*" over "continue crop agriculture and allied farm jobs anyway"		
	B: Coefficient	Exp B (odds ratio)	Wald chi-square	B: Coefficient	Exp B (odds ratio)	Wald chi-square
Farm landholding:						
Small farmer	−6.734	.001***	8.311	−2.971	.051*	3.065
Medium farmer	−7.293	001***	9.631	−1.392	.249	1.036
Likelihood ratio chi-square = 308.17***		Pseudo $R^2 = .86$		$N = 225$		

Note: The reference category is continue crop agriculture and allied farm jobs anyway
*Significant at 0.10
**Significant at 0.05
***Significant at 0.01

If a respondent increases his/her educational attainment by one unit, the relative chance of preference for "switch to or continue with saline shrimp farming" over "continue crop agriculture and allied farm jobs anyway" is expected to increase by a factor of 1.9 given the other variables in the model are held constant. It means educated people have two times higher probability to engage in saline shrimp culture if impacts of salinity become perpetual. Similarly, respondents who have never experienced harvest failure while culturing saline shrimp have about 20 times higher probability to prefer saline shrimp farming over crop agriculture and allied jobs if salinity problem becomes perpetual. By contrast, however, respondents who do not have experienced submersion of cropland by high tides are 0.034 times less likely to prefer saline shrimp farming over crop agriculture and allied jobs even if salinity problem becomes perpetual. Similarly, respondents who do not have experienced problems in double cropping a year are 0.162 times less likely to prefer saline shrimp farming over crop agriculture and allied jobs. Almost same way, smallholders (respondents) show their negative gesture to prefer saline shrimp farming over crop agriculture and allied jobs.

Model Output II: Who will prefer intensification of resources' extraction from Sundarbans over crop agriculture?

The model output shows that duration of fishing ($p = .00$), recovery period of cyclonic damage ($p = .00$), bonding with relatives ($p = .06$), types of occupation ($p = .02$), security concern ($p = .04$), membership of NGO ($p = .00$), seasonal migration ($p = .00$), power in local polity ($p = .04$), and farm/landholding size ($p = .08$) are the significant predictors of respondents' preference for intensification of resource extraction from *Sundarbans* over continue crop agriculture and allied farm jobs anyway as a broad strategy of adaptive response (LR chi-square = 308.17, pseudo $R^2 = 0.86$, $p < .001$) (Table 7). Other factors have very limited influence in this respect (Table 7: Model II).

For every one-year increase of experience of fishing of respondents in and around swampy mangrove forest Sundarbans, the probability to prefer "intensification of resource extraction from Sundarbans" over "continue crop agriculture and allied farm jobs anyway" is expected to increase by a factor of 1.3 given the other variables in the model are held constant. It means people who have been earning their livelihood from fishing in the open water (in and around swampy mangrove forest Sundarbans and adjoining bay area) are more likely to intensify their resources extraction if salinity increases. Similarly, respondents who have never migrated out seasonally for earning have about 14.70 times higher probability to prefer "intensification of resource extraction from Sundarbans" over "continue crop agriculture and allied farm jobs anyway" if salinity problem becomes perpetual. Much like the same way, respondents who are not members of any social group/ NGO have about 16.30 times higher probability to prefer "intensification of resource extraction from Sundarbans" over "continue crop agriculture and allied farm jobs anyway."

By contrast, however, respondents who suffer frequently from cyclonic storm are 0.16 times less likely to prefer "intensification of resource extraction from Sundarbans" over "continue crop agriculture and allied farm jobs anyway." In fact, to expedite the recovery period, they do not want to rely on Sundarbans-based aquatic resource extraction since making a good earning from those sources/ activities is highly uncertain. Moreover, immediately after the havoc caused by cyclonic storms, they often lack equipments and gears to go for fishing; also people avoid fishing at that time as fish feed on dead body of human beings and animals. Rather they try to migrate out to get job both in urban sector activities and in rural areas outside the coast where there is demand for wage labor. Similarly, respondents whose most of their close relatives do not stay close to their village are 0.18 times less likely to prefer "intensification of resource extraction from Sundarbans" over "continue crop agriculture and allied farm jobs anyway." It is because they have go for fishing or other resource extraction from Sundarbans for months; during their absence, their relatives often look after their families. For families whose close relatives stay away, the main earning member tries not to earn living from offshore fishing, but rather works in the locality as wage labor. Similarly, respondents who could not avoid giving ransom to pirates who kept them hostage while they were fishing in the Sundarbans area are 0.2 times less likely to prefer "intensification of resource extraction from Sundarbans" over "continue crop agriculture and allied farm jobs anyway" even if salinity increases. It is because the amount of ransom that they have to give in one time often is higher than what they earn in a year from fishing and other resource extraction activities from Sundarbans and its adjoining areas. Similarly among the respondents who do not have good connection (kind of patron-client relationship) with local political elites are 0.15 times less likely to prefer "intensification of resource extraction from Sundarbans" over "continue crop agriculture and allied farm jobs anyway" even if salinity increases. It is because while securing pass from the local forest department's office for entering swampy Sundarbans, often they have to pay 5–10 times more than the government revenue. But if they were backed by the ruling-party elites, they have to pay little more than the government revenue. Therefore, those who do not have good connection with local political elites often prefer working in crop agriculture and allied jobs. However, it is not very apparent why smallholders (respondents) have shown less interest for resource extraction from Sundarbans even if salinity will increase in the years to come. Probably they have failed to understand the damage that salinity may cause to their crop agriculture-based livelihood.

Policy Implications and Concluding Remarks

From the analysis of the foregoing findings, it could be interpreted that educated peoples are more likely than uneducated/less educated people to prefer adoption of saline water shrimp culture if salinity problem becomes perpetual. This finding confirms with the very fundamentals of risk-taking behavior of educated people. In fact, saline water shrimp production is a very lucrative business. However it needs capital and entrepreneurial skills to run efficiently. Then again there are lots of risk of harvest failure. For instance, viral attack, extreme weather conditions, such as high temperature, and submersion of shrimp production farms by cyclonic surges often cause harvest failure. Therefore, educated people may take into account these risk factors. Despite the risk of harvest failure, for those who have never experience such failure, it is very likely that they would use their skills, knowledge, and expertise and might continue to produce saline shrimp in the event of perpetual increase of salinity in the water and soil.

On the other hand, although at current level of salinity many respondents who do not experience very frequent inundation of their cropland by tidal water or who can make use of land for both wet and dry season rices/crops express their desire to continue crop agriculture and allied farm jobs, in practice when salinity would be perpetual, would they be able to strict to their current thinking? It is really a big question mark. Similarly, those who are smallholders and who do not have political connection, for them it is really hard to switch to shrimp farming. For this group who have shown their negative gesture toward saline shrimp, they are rational as well. As it is mentioned earlier that saline shrimp business involves a lot of risks and frequent harvest failures are very normal, except the large shrimp farm owners who have farm size within the range of 10–100 hectares, the marginalized or small farm owners with farm size below one hectare cannot afford the risk of harvest failure. Therefore, it is not unlikely that small farmers/smallholders would try to be strict to their ancestors' occupation of crop agriculture and allied jobs no matter how severe the salinity impacts would be. Another reason is that it is the crop agriculture and allied jobs with which they are habituated and they have limited sets of skills around these activities. Getting involved in a new venture like saline shrimp farming is different from their mind-set of occupational engagement. Therefore, even if salinity problem gets perpetual in the changing scenarios of climate and

SLR, very small fraction of the total coastal population would go for saline shrimp farming. Instead, from close consultation with many smallholders, it is revealed that they want saline-tolerant rices and other crop varieties to continue their known occupation in this juncture of their life.

From model II it is found that a large majority of the population who are mostly landless or posses very small amount (less than 30 decimals) of cultivable land and who are used to with fishing in the open water (rivers, canals, and bay in and around swampy mangrove forest Sundarbans) for generations are more likely to intensify their fishing in those areas in the event of lower catch due to increase salinity in water and soil. Similarly, poor people who have been extracting other resources such as *golpata* (nypah palm), honey, wax, and crab from Sundarbans for generations would also intensify their efforts to cope with the lower abundance of those forest products (both timber and non-timber). This would be the situation for few other groups of people. For instance, those who are not used to with seasonal migration to urban areas or in other resourceful rural areas outside the coastal zone would probably look for earning from swampy mangrove forest. In fact, the model result shows that this group might appear in the future as a major threat for the sustainability of resources of Sundarbans, because their intensions for extraction of these resources seem like very unsustainable. Therefore, it is very good time to explore the possibility of diverting this increasing stream of resource exploiters to unban sectors or other areas where there is seasonal demand for wage labors. In this connection, measures could be taken to enhance their existing skills, diversify their skills, and give them new set of skills through participatory training and capacity building projects. In this regard, both government and nongovernment entities such as private enterprises and NGOs could cooperate.

Almost similar situation would be created by poor people who are not member of any social groups or NGOs. Earlier findings (model II) reveal that this group of people have more inclination to exploit resources from swampy mangrove forest of Sundarbans if job opportunity gets reduced in the crop agriculture and allied sector due to increased salinity. Therefore, it could be argued that NGOs should consolidate their current awareness campaign as regards protection of global heritage site Sundarbans and at the same time could launch special programs of natural resource management for the coastal community. In this connection, the roles of donors and government agencies also must match with the changing demand of the protection of coastal resources without not undermining the livelihood avenues of poor and marginalized population.

There are positive sign as well as regards lowering dependency on resources of the swampy mangrove forest Sundarbans. Few distinct groups of people from poor and marginalized category who used to rely on both wage laboring in the agricultural sectors and resource extraction (specially fishing) from rivers, canals, and bay located in and around Sundarbans have started to go outside locality for urban sector jobs. This is not really a kind of seasonal migration but rather migration to avoid uncertainty of income from natural resource-based activities in the post disaster (e.g., cyclonic) period. One episode of cyclone of 3/4 category causes unprecedented damage to property and resources of poor and marginalized people.

It also destroys the places of resource extraction and fishing grounds and also seriously disrupts the transportation and communication channels of resource flow. Moreover, there is common prejudice among the coastal people that in the post disaster, especially in the post cyclonic periods, the fish in the rivers, canals, and bay located in and around Sundarbans feed on dead body of human beings and animals. Therefore, almost for 6 months in the post disaster period, poor fishers do not go for fishing as the demand for fish is less and so as the price. Therefore, many poor and marginalized people who used to depend on Sundarbans-based resources for livelihood in the normal period of life have shown strong inclination to move out for earning from urban sectors to expedite the recovery period in the post-disaster situation. This is because, in the post disaster situation, as the scope for resource extraction gets reduced, more and more poor and marginalized people would look for alternate avenues from urban sectors as the rural crop agriculture and allied activities would suffer from the accelerated pace of salinity as well. This behavior in fact opens up new opportunities for intervention to protect resources of Sundarbans and at the same time to ensure sustainable livelihood for the poor and marginalized population who used to depend on the abundance of natural resources of Sundarbans. In this respect a fresh program of capacity building that suits with the requirements of the urban sector's jobs could be launched in cooperation with business, NGOs, and local government agencies. Apart from this climate-compatible coastal physical infrastructure development program could be launched to give the poor and marginalized people an easy access to nearby urban centers for making their livelihood.

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Adaptation to Climate Change Effects Among Rural Women in Savannah and Forest Zones of Oyo State, Nigeria

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Contents

Abstract

The study assessed adaptation strategies to climate change effects among rural women in savannah and forest zones of Oyo State, Nigeria. A total of 117 rural women were randomly selected from the two randomly selected LGAs in the

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state. Data were collected through a structured interview schedule. A higher percentage in the savannah (88.2 %) than the forest (67.8 %) was in their active years (20–50 years). About 41 % (savannah) and 32 % (forest) had no formal education. Awareness of climate change was high (78.7 % and 69.6 %, respectively), while farming-related activities were the main livelihood. Also, 93 % admitted that climate change had a severe influence on their livelihoods through reduction in the amount of rainfall on their farmland. Respondents adopted different strategies such as multiple cropping, crop rotation, changing planting periods, storage of water for future use, and diversifying into other areas of livelihood to adapt to climate change effects. However, there was also a significant difference in the influence of climate change ($t = 4.605$, $p = 0.000$) and adaptation strategies ($t = 6.637$, $p = 0.000$) between the women in the two ecological zones. Adequate funding and locality-specific climate change-related information on adaptation strategies are recommended to be made available across the two ecological zones of the state.

Keywords
Climate change • Adaptation strategies • Rural women • Nigeria

Introduction

Climate change is one of the major environmental problems facing humanity. It is the cause of the mixture of extreme adverse phenomena such as drought, flood, and heat and cold waves. The problem of climate change in the world affects Nigerians and rural women most especially since they form the majority of producers and processors of agricultural crops, Nigeria being an agrarian society. At the same time, the change from traditional to intensive agricultural systems largely contributes to climate change. Land use changes, flooding areas for rice and sugarcane production, burning crop residues, raising ruminant animals, and using nitrogen fertilizers are all activities that release greenhouse gases into the atmosphere.

Developing countries are hard hit by climate change, particularly countries which depend largely on rain-fed agriculture. Climate change affects changes in plant growth and in production by promoting the spread of pest and diseases, increased exposure to heat stress (Fischer et al. 2002), changes in rainfall patterns, greater leaching of nutrients from the soil during intense rains, greater erosion due to stronger winds, and more wildfires in drier regions (Akonga 2001).

For Nigeria, climate change poses a great challenge to livelihoods and remains the overriding priority impetus to the promotion of sustainable economic development. Several authors have reported the negative impacts of climate change, most observed as change in weather patterns, increased rate of desertification, flooding, coastal erosion, increased water pollution and reduction in crops and livestock productivity, and consequently, lower income (Adejuwon 2004; Titilola et al. 1996; Nwajiuba et al. 2008; Ogbuehi et al. 2008)

According to IPCC (2001) projections for the humid tropics, rainfall is expected to increase in Southern Nigeria. However, in view of the expected increase in evaporation and evapotranspiration, there is likelihood of localized drought in parts of this humid area of the country. The effects of climate change to date have been small, but are projected to progressively increase in all countries and regions. In Nigeria, climate change often appears very obscure but it is real. According to Ihedioha (2007), parts of the outcome of climate change in some parts of the Nigerian economy are situational.

The gender-related impacts of climate change have also received some attention in the literature. Generally, the causes of climate change are closely related to struggles over resources between men and women in rural areas, but women are particularly affected because of their socially ascribed roles. Also in Nigeria, the altered rain patterns which disrupt planting seasons and adversely affect crop yields resulting in devastating consequences for livelihoods and economic security have been noted by indigenous peasant women. The end result of this is increased hunger and poverty to most rural women in Nigeria.

There are numerous significant linkages between gender and agriculture. Gender aspects in agriculture affect access to and control over resources, with consequences for food security as well as for market and policy decisions. In many countries, women's access to land is limited. At the same time, they account for 70 % of agricultural workers and 80 % of food producers (Fresco 1998). Bzugu and Kwaghe (1997) reported that women form the highest proportion of the economically active population in rural Nigeria and play an important role in agricultural activities, particularly in subsistence food production, where they contribute an estimated 60–80 % of the total labor used. Corroborating Bzugu and Kwaghe, Mabogunye (2010) asserted that an estimated 54 million of Nigeria's 78 million women are based in rural areas and make a living from the land. Also, because of their labor- and time-intensive work in order to care for their families, the share of women hit by poverty is high. Their responsibility for using and preserving land for food and fuel production and the resulting dependency on the soil make them vulnerable to climate change effects and consequences. Also it may be necessary to compare the degree to which climate change impacts the lives of rural women in the different ecological zones of Nigeria. This would be of great importance to develop principles and procedures to protect and encourage women in two of the distinctively different agroecological areas to national climate change mitigation and adaptation programs and projects. It has also become imperative to look into the extent and various ways by which change in climate has adversely affected livelihoods in the two ecological zones of the study area.

Oyo is one of the 36 states in Nigeria and it lies in the western part of the country. The state is divided into two ecological zones (rainforest to the south and savannah to the north) and is well suited for food crop production, as farming is being practiced by both men and women of the area. The bulk of food consumed in the southwestern part of Nigeria is being produced by farmers in Oyo State, while Oke-Ogun, in the savannah zone of the state, has been labeled the food basket of Southwestern Nigeria (Sangotegbe et al. 2011). Therefore, the assertion of Oluwasegun and Olaniran (2010) that Southwestern Nigeria is a region that feeds more than 45 % of the nation's population implies that the contribution of the Oyo to the nation's food security is significant. While the savannah zone favors mainly arable crops such as sorghum, maize, cowpea, and yam with some parcel of land, which supports tree crops, the forest zone favors the cultivation of some tree crops like cocoa and oil palm, alongside other crops as cassava, maize, and yam. Women are directly involved in the cultivation, processing, and marketing of these crops, especially the arable crops in both zones. However, processing and marketing are their important roles for cocoa and oil palm enterprises.

Objectives of the Study

The following specific objectives were achieved:

1. Assess the socioeconomic characteristics of the rural women in the study areas.
2. Determine the livelihood activities of respondents in Oyo State.
3. Compare the influence of climate change on the women's activities in the two ecological zones.
4. Identify the various adaptation strategies adopted by women in the two ecological zones of the study area.

Review of Relevant Literatures

Implications of Climate Change for Agriculture

Greater poverty impacts agriculture hugely since it hampers human energy/effort to plant and restricts capacity to afford necessary inputs. Smith (2006) notes that over 40 % of the world's people are unable or barely able to meet their needs for survival. Attainments of the Millennium Development Goals (MDGs) may therefore have been overtaken by events as the expiry is around the corner. It will result in greater poverty, wider discrepancy between rich and poor, sea level rises, and more precarious livelihoods challenging survival. Already, 2.7 billion people try to live on £1 or less per day. Smith (2006) argues that action on climate change is integral to poverty reduction. Such action requires both mitigation of the rate of change (Keller et al. 2005) and adaptation to that which does occur. Stabilizing CO_2 at 450 ppm (requiring cuts of 60–90 % in GHG emissions before 2100) may limit the mean global temperature rise to 2 °C. Mitigation of climate change is affordable; to stabilize at 450 ppm CO_2 would cost 1–4 % of global average GDP over 50 years. Kyoto protocol implementation would cost 0.1 % of GDP over 10 years.

Concept of Adaptation to Climate Change

Different authors have come up with different definitions of adaptation to climate change. Burton et al. (1998) define it as all those responses to climate change that may be used to reduce vulnerability. According to Burton (1997), adaptation to climate is the process through which people reduce the adverse effects of climate on their health and well-being and take advantage of the opportunities that their climatic environment provides. Downing et al. (1997) asserted that adaptation is synonymous with "downstream coping." Füssel and Klein (2002) defined it as all changes in a system, compared to a reference case, that reduce the adverse effects of climate change. IPCC (2001) defined adaptation to climate change as adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions, or activities to climatic change and variability. Adaptation strategies to climate change in this study are being viewed as a combination of adjustment and/or responses within the human capacity, put up to reduce the undesired impacts of climate change on the livelihood of the people, making use of the opportunities within the local environment.

Gender and Climate Change

There are numerous significant linkages between gender and agriculture. Gender aspects in agriculture affect access to and control over resources, with consequences for food security as well as for market and policy decisions. In many countries, women's access to land is limited. Patrilineal inheritance customs regulate land ownership and property rights and thereby influence control over land and food sovereignty. At the same time, women make up 54 % of the agricultural labor force worldwide, significantly more in the Global South. For example, 80 % of female employees and self-employed in sub-Saharan Africa are working in the agricultural sector.

Women make up a large number of poor people in communities that are highly dependent on local natural resources for their livelihood and are disproportionately vulnerable to and affected by climate change. Zabbey (2011) opined that women's limited access to resources and decision-making processes increases their vulnerability to climate change. Additionally, women in rural areas in developing countries have greater responsibility for household water supply, energy for cooking and heating, and for food security. Thus, women are negatively affected by drought, uncertain rainfall, and deforestation. Again, because of their roles, unequal access to resources, and limited mobility, women in many contexts are disproportionately affected by natural disasters, such as floods, fires, and coastal erosion (Zabbey. 2011).

Women are the main producers of the world's staple crops, providing up to 90 % of the rural poor's food intake and producing 60–80 % of the food in most developing countries. Maize, sorghum, millet, and groundnut yields have a strong association with the year-to-year variability of ENSO (El Niño-Southern Oscillation) in Africa. For Southern Africa, the productivity is expected to drop by 20–50 % in extreme El Niño years (Stige 2006). If global climate changes move more toward El Niño-like conditions, crop production in Africa will decline (Stige 2006). Insect outbreaks could increase due to changes in climate. For example, locust outbreaks in China are associated with cold and wet periods, floods, and droughts (Stige 2007). Climate variability, according to Stireman et al. (2005), also affects the relationships between parasite and host, and parasitoids are key agents of control of herbivore populations. An increase in pest outbreaks would not only reduce crop and milk yields but also add to the number of hours and resources women had to invest in pest control.

However, women are not just helpless victims of climate change, they are powerful agents of change and their leadership is critical. Women can help or hinder in dealing with issues such as energy consumption, deforestation, burning of vegetation, population growth and economic growth, development of scientific research and technologies, and policy making, among many others.

Methodology

The study was carried out within Oyo State. The two major ecological zones in Oyo State are the forest and savannah. Oyo State is located within the western region of the southern part of Nigeria. It covers a total of 27,249 km^2 of landmass. Oyo State enjoys the characteristic West African monsoon climate, marked by distinct seasonal shifts in the wind pattern. Between March and October, the state is under the influence of the moist maritime southwest monsoon winds, which blow inland from the Atlantic Ocean. This is the raining season. The dry season occurs from November to February, when the dry northeast trade dust harmattan winds blow from the Sahara desert. The state thus is characterized by two climate seasons, raining season and dry season.

Oyo State was stratified into rainforest and savannah zone (Table 1) being the two ecological zones in the state. In the rainforest zone, Saki West and Ido LGAs were purposively selected for being most predominantly savannah and rainforest, respectively. Of 10 wards in each of the LGAs, 30 % were selected, to give a total of six wards. Twenty-three villages were selected in all, while a total of 117 rural women were sampled. Table 1 presents the summary of the sampling procedure.

Structured interview schedule was used to obtain information from the women. Primary data were obtained on socioeconomic characteristics of respondents, livelihood activities, awareness of climate change, and impact of adaptation strategies to climate change effects. The level of awareness of climate change was measured by using a three-point scale indicating whether the selected impact items have increased (2), no change (1), or decreased (0). Perceived effects of climate change in the two area were measured in terms of yes = 0 or no = 1. Perceived

Table 1 Distribution showing sampling procedure and sample size in the two ecological zones of the study

Ecological zones	No. of wards	30 % of wards	No, of villages	10 % of villages	No. of household sampled per village	Total no. of respondents sampled
Savannah zone (Saki West local government area)	10	Ajegunle	51	5	5	25
		Keli	51	4	5	20
		Ogidigbo	41	4	4	16
Forest zone (Ido local government area)	10	Omi-Adio	30	3	7	21
		Akufo	29	3	5	15
		Apete	39	4	5	20
Total	20	6	241	23	31	117

effect of climate change was then operationalized as negative and positive, using the mean effect score as the benchmark. Adaptation strategies adopted by rural women in coping with the effect of climate change were measured as respondents indicated “yes” or “no” to a list of adaptation strategies employed and not employed, respectively. Scores of 1 and 0 were assigned to “yes” and 0 to “no.” An index of each of the influence of climate change effects and adaptation strategies was then obtained and abstracted to interval levels of measurement. The mean scores of influence of climate change as well as farmers’ level of adaptation strategies were then compared, each between women in savannah and forest zones of the state, as stated in hypotheses 1 and 2, respectively.

Conceptual Framework

Figure 1 below presents the conceptual framework that relates the negative effects of climate change and their adaptation strategies to these effects. This is not to imply that climate change is only associated with negative consequences. However, the study focuses on only the various negative effects of climate change against which rural women in the two ecological zones have developed adaptive measures. The framework borrows from a number of frameworks that have been used in analyzing risk, vulnerability, and poverty (Smith et al. 2005 and Hoddinott and Quisumbing 2003). The socioeconomic characteristic of an individual has an influence on the various forms of livelihood activities (livelihood strategies) a typical rural dwellers engages in. In recent years, farming is becoming a far less potent source of livelihood in the rural areas of many sub-Saharan African nations; therefore, multiplicity of these activities has become a trend. It is therefore expected that, for example, membership of social organization could avail a rural dweller access to credit facilities and extension education. These and many more opportunities derivable from being members help an individual to diversify into other forms of livelihood

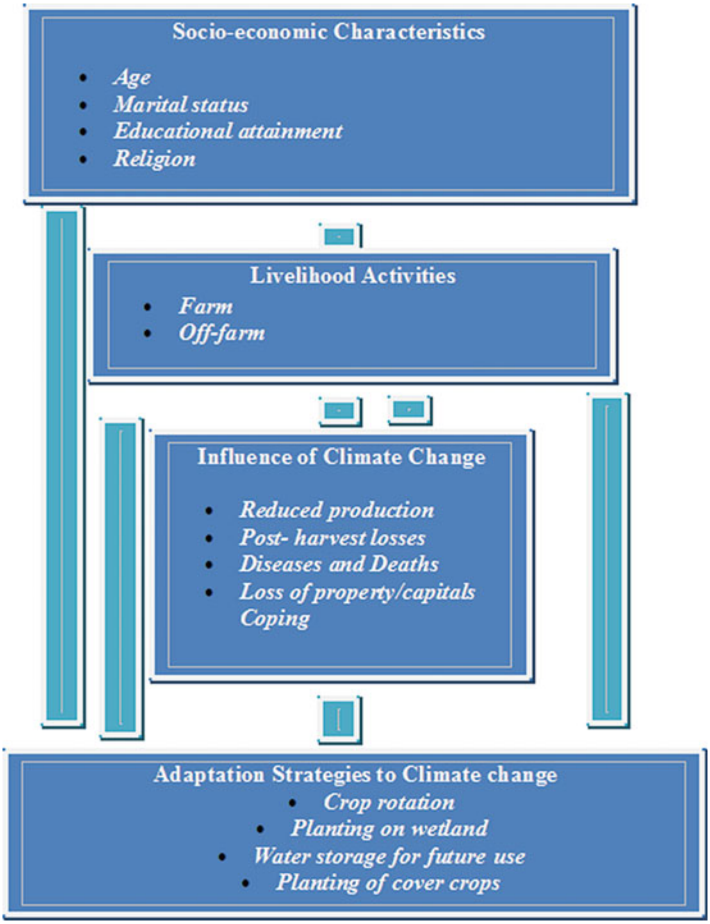

Fig. 1 Conceptual framework for adaptation strategies to climate change of women in two ecological zones of Oyo State. Source: Authors' idea

activities, since assets (in this case, social asset) determine to a large extent an individuals' livelihood activity in terms of number and type. Smith et al. (2005) support this notion by positing that in the rural communities, the capacity to resist poverty and improve livelihoods often depends on the opportunities offered by natural resource-based production systems as conditioned by wider economic, institutional, and political environment. Bebbington (1999) posited that these assets are not simply resources that people use in building livelihoods but they are also assets that give them capabilities. For example, possession of human capital is not only the means people produce more and more efficiently, it also gives them the capability to engage more fruitfully and meaningfully with the world (Sen 1997).

The framework also establishes a direct and vice versa relationship between these livelihood activities and the influence climate change has on the people.

This is because climate-related shocks often affect stock of livelihood assets, which eventually have their tolling effects on livelihood activities. These often result in reduced production, poor health, insecurity, loss of capitals, poor harvest, and post-harvest losses. On the other way round, these resultant effects of climate change affect the extent to which the people are engaged in one form of livelihood activity or the other. For example, a woman farmer with poor health condition (an example of influence of climate change) has less human capability to work and therefore limit her engagement in livelihood activities and even her holding of assets. At the last level of the framework are the adaptation strategies to climate change of rural women which are a function of the kind of influence climate change has on their livelihood activities. This partly agrees with Smith et al. (2005) that depending on the assets (as a proxy for activities) the people have access to which defines livelihood activity opportunities, a household will then choose a set of adaptation strategies to climate change effects. Bebbington (1999) posited that assets are not simply resources that people use in building livelihoods but also gives them capabilities. Adaptation strategies are also directly influenced to a very large extent by some socioeconomic characteristics such as educational status, membership of social organization, and access to credit facilities. Also, the level and how effective are the adaptation strategies of the people, to a large extent, impact upon their livelihood activities and assets in terms of extent of use (for activities) and value and number (for assets) for building resilience against climate change effects.

Results and Discussion

Table 2 reveals that 26.2 % and 19.3 % of the respondents were 30 years and below in savannah and forest zones, respectively, while 33 % and 30 % falls within middle-age range of 41–50 years. The mean age of the women in savannah zone was 40 years, while those from forest zone were 43 years. The result implies that more of the rural women from savannah zone (88.2 %) are in their active age of 20–50 years when compared with respondents from forest zone (67.8 %); hence, they can actively engage in productive activities and thereby contribute effectively to food production in Nigeria. The result also shows that 80.3 % and 63.4 % of the respondents from savannah and forest zones respectively were married. This implies that since women in the two zones were predominantly married, this could influence the adaptation strategies of the majority through spousal supports and thereby reduce the effects of climate change on their activities.

Also, 41 % and 34 % of the respondents from savannah and forest zones respectively do not have formal education, while 32.8 and 32.1 % respectively had primary education. This shows that there is a very large case of illiteracy, as level of literacy was low. Accessing relevant information through the use of the modern-day ICTs as well as the print media may therefore be difficult for the respondents. The result further shows that 55 % and 44 % of the respondents from the respective zones were Christians, while 42.6 % and 53.6 % were Muslims. The result reveals that 52.6 % and 66 % of the women in savannah and forest zones

Table 2 Distribution of respondents according to their socioeconomic characteristics

Variables	Savannah zone		Forest zone	
Age (years)	Freq	%	Freq	%
20–30	16	26.2	11	19.8
31–40	18	29.4	10	18.0
41–50	20	32.6	17	30.0
51–60	2	3.2	14	25.0
61–70	5	8.0	4	7.2
Marital status				
Single	3	4.9	2	3.6
Married	49	80.3	36	64.3
Widowed	5	8.2	12	21.4
Divorced	4	6.2		10.7
Educational attainment				
No formal education	25	41.0	19	33.9
Primary education	20	32.8	18	32.1
Secondary education	11	18.0	6	10.7
Tertiary education	5	8.2	13	23.2
Religion				
Christianity	34	55.7	25	44.6
Islam	26	42.6	30	53.6
Traditional	1	1.6	1	1.8
Membership of socio-organizations[a]				
Trade union	16	26.2		26.8
Corporative society	3	4.9	15	3.6
Religious association	32	52.5	2	66.1
Tribal group	6	9.8	37	3.6
Age group	1	1.6	2	–
Other social organizations	3	4.9	–	–

Source: Field Survey, 2011
[a]Multiple response option

respectively belongs to various religious groups in their communities and this constitutes a greater proportion compared with other social groups in the zone. This is a clear indication that most of the women will have quick access to information about their community, family, and other areas of concern. Also women join voluntary formal groups to be better informed and for economic gains.

Livelihood Activities Engaged in by Respondents

Table 3 reveals that in the savannah zone, 41.0 % of the respondents were fully involved in crop farming, while 18.0 % are occasionally involved. Few of the women (6.6 %) were fully engaged in rearing of animals, while 50.8 % of the women occasionally rear livestock such as goats, sheep, and fowl. About one third (34.4 %) of the

Table 3 Distribution of respondents by livelihood activities (farming-related activities) in savannah and forest zones

	Fully		Occasionally		Not		Fully		Occasionally		Not	
	Savannah zone						Forest zone					
Livelihood activities	F	%	F	%	F	%	F	%	F	%	F	%
Crop farming	25	41.0	11	18.0	25	41.0	29	51.8	7	12.5	20	35.7
Livestock rearing	4	6.6	31	50.0	26	42.6	–	–	34	60.7	22	39.3
Crops processing	8	13.1	21	34.4	32	52.5	17	30.4	25	44.6	14	25.0
Marketing of farm produce	21	34.4	21	34.4	19	31.1	29	51.8	16	28.6	11	19.6
Gathering and sales of firewood	5	8.2	5	8.2	51	83.6	–	–	6	10.7	50	89.3
Gathering and sales of snails	–	–	1	1.6	60	98.4	2	3.6	28	50.0	26	46.4
Hired labor	3	4.9	11	18.0	47	77.0	1	1.8	7	12.5	48	85.7
Fish farming	1	1.6	1	1.6	59	96.7	–	–	–	–	56	100
Fish and feed production	–	–	3	4.9	58	95.1	–	–	2	3.6	54	96.4
Harvesting of farm produce	7	11.5	20	32.8	34	55.7	7	12.5	20	35.7	29	51.8
Others	2	3.2	1	1.6	56	91.8	2	3.6	2	3.6	52	92.9

Source: Field survey, 2011

women also reported significant involvement and direct marketing of their farm products such as cassava, maize, palm produce, etc. These are farm products cultivated by the women or by their husbands, thereby eliminating the position of middlemen and more profits are made. The results agree with Dercon and Krishnan (1996), Bryceson and Jarnal (1997), Little et al. (1998), and Barret and Webb (2001) who argue that farming on its own rarely provides a significant means of survival in rural areas of low-income countries including Nigeria. Rural livelihood diversification also serves as means of spreading risks associated with climate change among respondents in the study area. The result also shows that majority of the respondents do not engage in hired labor activities (77 %), fish farming (95.1 %), and harvesting of farm produce (95.7 %). The implication of this is that these activities are considered for the men folk since it requires lot of energy.

Table 3 further shows that of all the farming-related livelihood activities in the forest zone, larger proportion of the respondents were fully engaged in crop farming (51.8 %), crop processing (30.4 %), and marketing of farm produce (51.8 %). Also, none of the respondents was fully involved in livestock rearing, gathering and sales of fuelwood, fish farming, fish processing, and hired labor work. This implies that majority of the women in the zone derived their living through farming; hence, their survival depends on agricultural land which must be rich and fertile in order to increase productivity. The result concurs with the study of Asunmgha and Nwosu (2006) and Ajeih and Uzokwe (2007) that women play a leading role in agricultural enterprise, contributing about 58 % in southwest and 88 % in north-central zones, with involvement in virtually all activities, namely, hoeing, planting, weeding, harvesting, transporting, storing, processing, marketing, and domestic chores.

Influence of Climate Change on the Livelihood Activities of the Respondents in the Two Zones

Table 4 reveals that majority (80.3 % and 100 %) of the respondents residing in savannah and forest zones respectively had experienced an increase in intensity of sunlight over the years. The result shows that majority of women in savannah zone (63.9 %) and 100 % of women in forest zone also experienced decrease in the frequency of rainfall. In a study in the northern part of Nigeria, Ojo et al. (2001) showed a decrease in rainfall in the range of about 3–4 % per decade since the beginning of the nineteenth century. The result also reveals that 63.9 % of women in savannah zone and 82.1 % in forest zone lamented an increase in incidence of pest and diseases, while very few (6.8 % and 1.6 % of women) in these zones reported that there is no change being witnessed. This implies that change in climate favors emergence of pest and disease which feeds on farmers' crops leading to decrease in farm yield and consequently lower income of the farmers. WHO (1990) supported this view that adequacy of food production could be affected by reduction in the quantity of water available for irrigation, loss of farmland through rise in sea level, changes in crop yield, livestock production, and geographical shifts in the agroclimatic zones suited to the successful cultivation of

Table 4 Distribution of respondents' awareness on climate change

Variables	Savannah zone						Forest zone					
	Increase		Decrease		No change		Increase		Decrease		No change	
	F	%	F	%	F	%	F	%	F	%	F	%
Increased intensity of sunlight	49	80.3	11	18.0	1	1.6	56	100	–	–	–	–
Increased frequency of rainfall	21	34.4	39	63.9	–	–	–	–	56	100	–	–
High incidence of pest and diseases	39	63.9	18	29.5	4	6.8	46	82.1	9	16.1	1	1.6
High incidence of skin and airborne diseases	40	65.6	7	11.5	14	23.0	14	25.0	12	21.4	30	53.6
Heat stress on human productivity	46	75.4	6	9.8	9	14.8	52	92.9	–	–	8	13.1
Reduced availability of forest products	12	19.7	41	67.2	8	13.1	1	1.8	44	78.6	11	19.6
Increased cases of soil erosion and flooding	8	13.1	21	34.4	32	52.5	4	7.1	18	32.1	34	60.7
Reduced availability of portable water	8	13.1	45	73.8	8	13.1	34	60.7	20	35.7	2	3.6
Loss in crop productivity	42	68.9	12	19.7	7	11.5	33	58.9	14	25.0	9	16.1
Loss of animal productivity	46	75.4	6	9.8	9	14.8	33	58.9	14	25.0	9	16.1

specific crops. The study further revealed that 67.2 % and 78.6 % of the respondents from savannah and forest zones respectively reported a decrease in availability of timber and other forest products such as mushrooms, snails, breadfruit, and so on. A large number (68.9 % and 58.9) of the women in the respective zones reported increasing cases of crop losses and declining animal productivity. The implication of this is that there would be a decrease in supply of animal protein to the community which could lead to insufficient protein, deficiency diseases, and low income with consequent poverty being on the increase. Kurukulasuriya et al. (2006) and Ole et al. (2009) asserted that analysis of 9,000 farmers in 11 African countries predicted falling in farm revenues with current climate scenarios. Also Butt et al. (2005) predicted future economic losses and increased risk of hunger due to climate change.

Adaptation Strategies to Climate Change

Due to the influence of climate change on livelihood activities, women in the two ecological zones of the study employ different adaptation strategies to climate change effects on their activities. The study reveals that adaptation strategies employed by the respondents to various extremes of climatic variables varied across the two ecological zones of Oyo State. In the savannah zone, for example, the most important adaptation strategies included water storage for future use, diversification into other activities, and changing planting dates. This establishes the low level of water available for the crop plants, as well as for other livelihood and domestic activities of the rural women in the study area. It also implies the irregular rainfall annual calendar. On the other hand, while diversification into other activities was the most used adaptation strategies to climate change, practicing multiple cropping and changing planting dates were also important adaptive measures against climate change effects. These results are in line with Molua (2008), Rudolf and Hermann (2009), and Apata et al. (2009) who reported that main strategies for reducing climate risk is to diversify production and livelihood systems like soil and water management measures.

In the two zones, however, the least adopted adaptation strategies to climate change included rearing snail and/or grass cutter, use of fertilizer on farmland, as well as planting of *Jatropha* to help conserve water through reduction of evapotranspiration. The low-level adoption of use of fertilizer may be due to low access to production resources which very often are the cases in sub-Saharan Africa. This is in line with Ajani (2008) who asserted that despite significant contributions of women to economic development and the household, overall, they have less access to land, capital, credit, technology, and training than men do. This significantly entrenches poverty in the female gender. It also agrees with Sangotegbe et al. (2012) who reported lack of access to fertilizer as an important constraint limiting food crop farmers' adaptive capacity to climate change in Oke-Ogun, an area in the savannah region of Oyo State (Table 5).

Table 5 Distribution of respondents according to adaptation strategies to climate change in savannah zone

Adaptation strategies	Savannah			Rainforest		
	F	%	Rank	F	%	Rank
Crop rotation	27	44.3	5	37	66.1	4
Planting of trees	20	32.8	8	8	14.3	11
Cultivating wetlands (Akuro)	25	41.0	7	14	25.0	8
Planting early maturing crop	15	24.6	9	17	30.4	7
Use of fertilizer on farmland	6	9.8	13	11	19.6	10
Practicing multiple cropping	30	49.2	4	39	69.6	2
Planting improved seed variety	11	18.0	10	14	25.0	8
Planting of *Jatropha*	11	18.0	10	3	5.4	13
Water storage for future	55	90.2	1	23	41.1	6
Changing planting dates	31	50.8	3	39	69.6	2
Rearing snail and/or grass cutter	7	11.5	12	6	10.7	12
Planting of cover crops	27	44.3	5	27	48.2	5
Diversification into other activities	46	75.4	2	43	76.8	1

Source: Field survey, 2011

Hypothesis 1

Ho$_1$ There is no significant difference in the influence of climate change on rural women in the two ecological zones.

Result shows that there is a significant difference in the influence of climate change on the activities of rural women in the two ecological zones (t = 4.605, p = 0.000), with the effects being more in the forest zones. The implication of this is not far from the fact that savannah zone experiences shorter duration of rain period with longer period of dry season than forest zone which enjoys abundance of rain. This could mean more hardships to the rural women in this zone (savannah), many of whom depend on the natural sources for water and other resources as sources of livelihood and household energy needs (Table 6).

Hypothesis 2

Ho$_2$ There is no significant difference between the levels of adaptation strategies adopted by rural women in the two ecological zones.

The findings further reveal that there is significant difference between adaptation strategies adopted by rural women in the two ecological zones (t = 6.637, p = 0.000), with the forest zone adopting a higher level of adaptation measures than their savannah counterparts. This may be expected since rural women in the forest zone of the state experienced higher effects of climate change. It should however be noted that majority of the adaptation strategies being adopted to reduce climate

Table 6 *t*-test analysis of the influence of climate change on rural women in the two ecological zones

Variables	Mean	Degree of freedom	t-value	p-value	Mean difference	Standard deviation	Decision
Savannah	8.10	116	4.605	0.000	8.11	2.160	Significant
Forest	16.21						

Table 7 *t*-test analysis on adaptation strategies adopted by rural women in the two ecological zones

Variables	Mean	Degree of freedom	*t*-value	*p*-value	Mean difference	Standard deviation	Decision
Savannah	13.202	30	6.637	0.000	5.129	4.303	Significant
Forest	18.331						

change effects on the activities of women are those within their very limited economic power. It therefore suggests that the higher level of adaptation strategies were informed by the higher level of effects in the forest, rather than being indicative of higher level of access to resources (Table 7).

Conclusion and Recommendations

Women in the two agroecological zones are engaged in farming-related activities as their means of livelihood although very few of them engage in non-farming-related activities such as trading, hair-plaiting, tailoring, pottery, craft work, and tie-dye. The result of the research reveals that majority of the respondents in the two zones agreed to have been highly affected by climate change, in their various livelihood activities. Influence of climate change on respondents' livelihood activities and adaptation strategies adopted against climate change effects were both higher in the forest than in savannah zones of the state. However, adaptive capacities of the women were limited as strategies to climate change were restricted to those within the limited local resources available to the rural women in the two ecological zones of Oyo State.

Recommendations

Based on the results and conclusion of the study, the following recommendations are important:

1. Government should provide irrigation facilities especially in the drier region of the state (savannah zone) so as to boost agricultural activities during dry season.
2. The use of alternative energy fuel such as biofuel for domestic and household cooking should be encouraged among women.

3. Affordable technology that will adequately help rural women to cope with negative effects of climate change such as improved planting material, drought-resistant crop, planting early maturing varieties, and cultural means of reducing infestation of pest and diseases should be within the reach of the rural women.
4. Rural women should be encouraged to form groups where they can get access to short- term credit facilities at lower interest rates to help finance agricultural production and as such improve their lives and that of their family.
5. The Nigerian government should develop a gender strategy, promote women representatives as official focal points, invest in gender-specific climate change research, and establish a system for the use of gender-sensitive indicators and criteria for governments in national adaptation planning.

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Agricultural Extension and Adaptation Under the "New Normal" of Climate Change

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Abstract

Adapting to climate change is the most serious challenge facing our species. The scale is global, trajectory of onset uncertain and impacts potentially catastrophic (IPCC 2013). As further evidence emerges and as the scramble to adapt to the 'new normal' intensifies, persistent problems, past failures and new challenges have the potential to converge in a perfect storm. In response, extension and advisory service (EAS) providers have a key role to play as a critical link between farming populations and sources of new information and tools, so that practices can be appropriately adapted. This chapter outlines the challenge of adapting to climate change, identifies past and present points of EAS engagement, and proposes future responses, with a focus on the constraints and conditions of smallholder farmers in the tropics, and the natural resource base upon which agriculture depends.

Keywords

Agriculture extension and advisory services • climate change adaptation • human capacity development • information communication technologies • policy coordination • scaling interventions • systems research • technology switching points • technology transfer/dissemination

Introduction

Since the domestication of crops and the emergence of sedentary societies, adapting to climate change is the most serious challenge our species has faced. The scale is global, the potential impacts catastrophic, the time frame of onset largely unknown, and the threat of delayed action real (IPCC 2013, 2014). As further evidence emerges, we will have to continually redefine our understanding of problems and formulate responses.

Extension and advisory service (EAS) providers have a key role to play as a critical link between farmers and sources of new information and tools and in aiding farming populations to anticipate and adapt their practices in response to the challenges of climate change. Public extension systems will need to improve, to change the perception that they are unimportant and outdated. Private-sector interests will need to adjust and respond to shifting opportunities, and nongovernmental organizations (NGOs) and donors will need to join forces with others to achieve broader impact. As the scramble to adapt to the *new normal* intensifies, persistent problems, past failures, and new challenges have the potential to converge in a perfect storm. In response, all involved in agricultural adaptation will need to elevate the level and quality of their efforts.

This chapter outlines the challenge of adapting to climate change, identifies past and present points of EAS engagement, and proposes future responses, with a focus on the constraints and conditions of smallholder farmers in the tropics and the natural resource base upon which their livelihoods depend.

Box 1: Definitions of Key Terms Used in This Brief in the Context of Climate Change

Vulnerability: "[T]he degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change" (IPCC 2007a).

Resilience: "The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner. . ." (IPCC 2012).

Adaptation: "In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects. . ." (IPCC 2012).

Mitigation: The efforts undertaken to "reduce anthropogenic [greenhouse gas] emissions or to enhance natural sinks of greenhouse gases" (IPCC 2007b).

The *New Normal*: The Biophysical Forces

Before they can prepare for and respond to global climate change, EAS providers must first understand the essential nature of climate change and the associated challenges. The rapid 20–25 % downturn in precipitation across the West African Sahel that occurred around 1970 and lasted through the 1990s provided a glimpse of what the future may hold. Global climate change, however, will be different.

In the current context, and barring the onset of abrupt climate change, we are unlikely to see such a sudden shift. Climate change is a process that will continue well into the next century with impacts felt over the next millennium. Climate change is also nonlinear and highly complex, with layers of feedback loops and unknown "tipping points" that, when exceeded, offer no retreat. Moreover, changes will continue on multiple fronts – air temperature and volume and patterns of precipitation, as well as other weather features. Climate change should also be understood as permanent; there will be no return to prior conditions over the course of individual human lifetimes (IPCC 2013).

Unlike challenges we have confronted in managing natural resources in the past, in the case of climate change, we have neither the means to readily affect the near-term rate or direction of change nor sufficient knowledge to anticipate the long-term synergistic effects within linked physical and natural resource systems.

Climate change will exert increasing pressure on our ability to meet other major challenges, feeding the world's growing population, which is expected to reach 9.6 billion by 2050, being paramount (UNDESA 2013). The environmental impacts of meeting rising food demand will be intensified as global warming and changes in associated climate features amplify the stressors placed on vulnerable and overburdened natural resource systems, leading to unknown interactions and feedback in the complex web of relationships among social, environmental, economic, and food systems with "uncertain consequences" (Ericksen et al. 2009). This situation is particularly troubling for people who are surviving on already degraded systems.

EAS providers will need to contend with the effects of two dimensions of climate change: ***climate change trends*** *and* ***weather disruption****.*

Climate Change Trends (Slow-Onset Systemic Changes)

Greenhouse gases: Increased concentrations of greenhouse gases (GHGs) prevent solar radiation reflected from the earth's surface from escaping the atmosphere. Carbon dioxide (CO_2) is the primary GHG emitted through human activities. The agricultural sector is a significant contributor to the problem. Taken together, the deforestation associated with agricultural expansion and direct and indirect energy use (including food transportation, processing and preparation), the agricultural sector is responsible for roughly one third of all GHG emissions (IPCC 2007b; USEPA 2006). To avoid triggering significant climate change, the upper limit of atmospheric CO_2 concentration is estimated to be around 350 ppm (Hansen et al. 2008). Concentrations have been rising steadily, 2 ppm per year over the past 15 years, and reached 400 ppm in May 2013 (NOAA 2013). At this rate, CO_2 levels are on track to meet the IPCC's most pessimistic projection for 2100 (IPCC 2013). Such high levels of CO_2 are expected to have a catastrophic effect on the planet's ecosystems. One hope is that if we can reduce future GHG emissions, we can mitigate the risk of even more distant changes to the climate. But even if all additional emissions were eliminated, 15–40 % of the warming effect from past emissions will continue for the next 1,000 years (IPCC 2013). And we have barely begun the serious work of reducing emissions.

Global warming: The primary outcome of rising atmospheric levels of CO_2 is an increase in land and sea surface temperatures – global warming. Historical records show a close tracking of air temperatures with atmospheric CO_2 levels (see Fig. 1). Over the past 60 years, average global air temperature has risen by 0.7 °C; temperatures over landmasses and in the high latitudes have risen by double this amount (IPCC 2007a, 2013). Decadal warming–cooling cycles in the south Pacific, currently in a cooling phase, are thought to be responsible for the recent slowdown in the rise of global air temperatures (Kosaka and Xie 2013). When the effect subsides, more rapid warming will likely occur.

Rising air temperatures trigger important secondary effects: These include (i) changes to seasonality, especially the onset and duration of warm seasons in northern latitudes; (ii) changes in the onset and duration of rainy seasons in the mono- and bimodal rainfall areas of the tropics; (iii) melting of the polar ice caps, northern latitude ice shields, and high-altitude glaciers worldwide, leading to changes in the timing and volume of freshwater discharge and rising sea levels; and (iv) more water cycling through the climate system (since warmer air carries

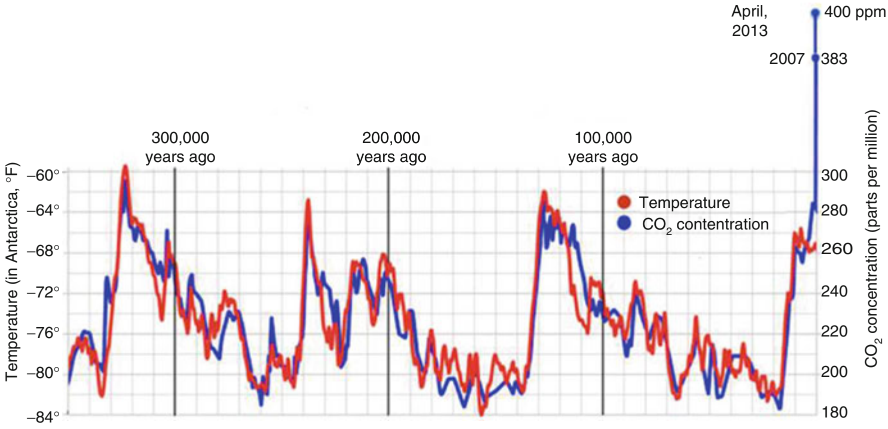

Fig. 1 CO_2 and global temperatures (Source: Modified from Southwest Climate Change Network, The University of Arizona (www.southwestclimatechange.org/figures/icecore_records), modified from Marian Koshland Science Museum of the National Academy of Sciences (www.koshland-science-museum.org))

more moisture), but with nonuniform distribution – in general, wet areas are projected to get wetter and dry areas drier.

Tertiary impacts of these changes on agriculture: These include (i) disruption of plant–pollinator and pest–predator relationships, altering the geography of pests and diseases, caused by rising air temperatures and changes in seasonality; (ii) higher daytime and nighttime temperatures affect plant maturation and plant respiration – the resulting yield declines (e.g., see Lobell and Asner 2003; Peng et al. 2004; Easterling and Apps 2005) will erase any positive effects on photosynthesis from higher concentrations of atmospheric CO_2 (see Fig. 2); (iii) by 2100, average growing-season temperatures are projected to exceed the temperature tolerances for many crops in locations where they are now grown (see Battisti and Naylor 2009; Gourdji et al. 2013); (iv) the decline and eventual loss of glacial water sources will drastically affect the systems that depend on these for irrigation, especially in high-population areas in Asia; and (v) rising sea levels will inundate low-lying coastal areas and islands, causing increased saltwater intrusion in coastal river and groundwater systems, eventually displacing tens of millions of people in flood-prone areas and potentially affecting a tenth of the world’s population – those living within 10 m of sea level (McGranahan et al. 2007).

Our understanding of when, where, and how these changes will be felt is still nascent (IPCC 2014). These general trends, however, will continue as long as we continue to emit substantial amounts of GHGs and long after. The very act of feeding the world’s population (agriculture) is a major source of emissions, and this effect will likely increase, not decrease, as we struggle to increase food production by the required 60–70 % by 2050 (FAO 2009; USAID 2013).

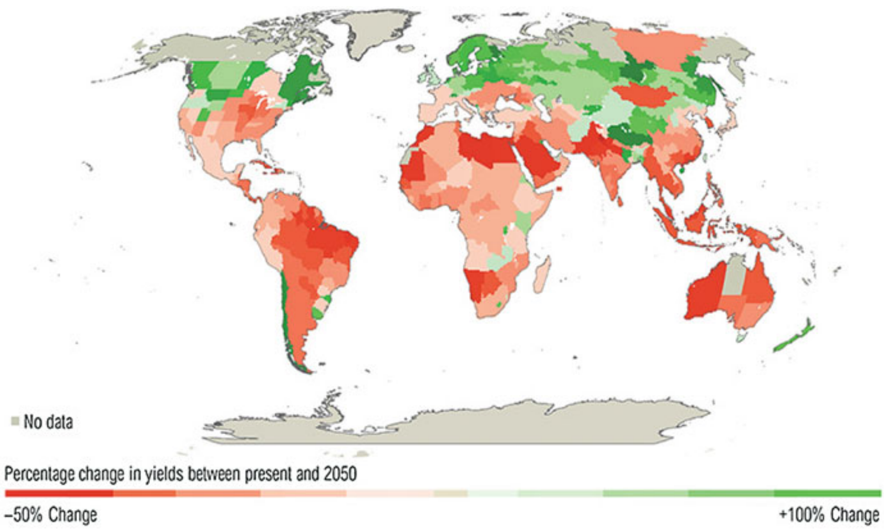

Fig. 2 Projected impact of a 3 °C temperature increase on crop yields (Source: World Bank 2010)

Weather Disruption (Extreme and Aberrant Weather Events)

More frequent and severe and at unpredictable times and places: Severe weather events – droughts, floods, hurricanes/cyclones/typhoons, and heat waves – are occurring with increased frequency, duration, and severity (IPCC 2012). The additional moisture carried by warmer air and the increased energy stored in the oceans (i.e., 90% of the solar energy trapped by GHGs) are leading to more intense and frequent storm events, as well as the systemic changes to rainfall described above (IPCC 2013). Extreme heat events in areas such as West Africa, for example, which typically occur once in 20 years, are predicted to occur every 2 years by the end of the century (IPCC 2012), and historically rare, once-in-50-years, once-in-100-years, and once-in-300-years events will become commonplace (see Fig. 3). EAS providers will increasingly be called on to assist with relief efforts for affected populations in the wake of these unpredictable and severe weather events (Shepherd et al. 2013).

Depletion and reduced resilience: Increasingly disruptive weather patterns will wear down the resilience of human systems and lead to the ecological restructuring of natural systems. Productivity will decline in some areas; natural resources and financial reserves will be depleted and unavailable for investment in long-term welfare improvements. Countries whose economies depend on rain-fed agriculture will be especially vulnerable; for example, in the Africa region, between 1960 and 2000, gross domestic product tracked closely with the rise and fall of annual rainfall levels (Barrios et al. 2003). At the farm level, investments in agricultural enterprises, especially those that depend on vulnerable local resources (such as seasonal water sources), will become increasingly risky.

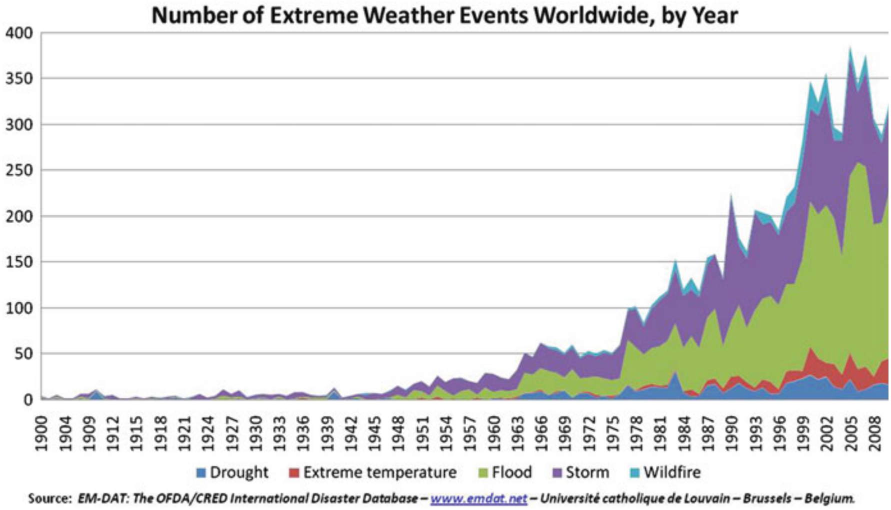

Fig. 3 Numbers of extreme weather events globally, by year (Credit: Naam 2013)

Implications for Smallholders and the Rural Poor

Global climate change has sobering implications for natural resource management (NRM) and our long-term ability to feed ourselves. It also calls into question our continued ability to rely on agriculture for long-term poverty reduction and economic growth (World Bank 2008, 2010).

One of the hallmarks of the vitality of rural communities and smallholders is their ability to respond and adapt to changes that affect their livelihoods. Older villagers and more experienced farmers have noted changes in local climate and weather for several decades. Changes that are compounding the effects of expanded crop production and meeting fuelwood needs, leading to soil erosion and declining fertility through reduction and abandonment of fallow periods, increased insect pressures and incidence of disease, all related to the intensification of resource extraction (Bryan et al. 2009; Ebi et al. 2011; Gbetibouo 2009).

The fewer assets that rural families have – human, financial, natural, social, political, physical – the more challenging it becomes for them to cope with change and the longer it takes for them to recover from even modest shocks. Many communities and households already struggle to survive due to ongoing degradation of natural resources. The negative impacts of climate change trends and weather disruptions will further deplete the natural and financial assets of the rural poor, increasing their vulnerability (Barrett and McPeak 2006).

Collectively, legal tenure systems in many countries also undermine farmers’ control over natural resources. Ineffective national policies and local management structures further weaken farmers’ ability to manage natural resources, increasing their vulnerability to climate-induced trends and shocks. In contrast, within the

Box 2: The Lessons of Hurricane Mitch

The events in the aftermath of Hurricane Mitch in Central America in 1998 illustrate the importance of timing and scale. Families who had previously resisted planting live contour barriers to stem runoff and erosion lost their hillside plots in the hurricane while neighboring plots were protected by well-spaced vetiver hedges and rock barriers. A large multiagency research project on farmer responses to Hurricane Mitch found that plots under conservation agriculture practices sustained 58–99 % less damage, retained 28–38 % more topsoil, and suffered two to three times less surface erosion than conventionally managed plots. Seeing the differences, households that had previously resisted changing NRM practices immediately began to demand training and the adoption of *new* practices and technologies soared (World Neighbors 2000).

Lesson 1: Efforts to bring about behavioral change should to be targeted at the appropriate scale – in this case, hillsides within a watershed.

Lesson 2: Use observable evidence of climate change to focus farmers' attention on the importance and interrelations of NRM practices and agricultural management alternatives – i.e., capitalize on the teachable and learnable moments.

context of climate change, there is a growing need to link individual agricultural decisions with larger landscape and land-use management challenges.

Individuals and communities can be slow to implement changes in NRM, especially in locations with high proportions of vulnerable households and where there are no immediately observable benefits in productivity (Marenya and Barrett 2007; Shiferaw et al. 2009). Unfortunately, the benefits of most changes in NRM take time to manifest and are easily masked by seasonal stresses. Changes in local weather patterns, including more frequent severe events, will push smallholders to take up new NRM practices more quickly. Indeed, disasters can trigger rapid, widespread behavioral change that EAS providers must be prepared to capitalize on (see Box 2).

The Challenges of Climate Change for EAS Providers

The nature and range of professional challenges facing EAS providers will increase as the cumulative effects of climate change manifest themselves, including helping vulnerable farmers and rural communities to:

(a) ***Adapt*** their livelihoods to current and future changes in local weather conditions and the evolving status of natural resource systems.
(b) Strengthen the (bio)physical and social ***resilience*** of natural and human systems to withstand and recover quickly from increasingly frequent and severe weather events.

(c) ***Mitigate*** risks of further climate change by conserving existing carbon stocks, reducing CO_2 emissions from agriculture, and helping to sequester atmospheric CO_2 in trees and soil organic matter.

EAS Key Challenge No. 1: Determining the Technological and Adaptive Practice Switching Points

Extension and research programs must determine what proportion of limited human and financial resources to allocate to landscape-level versus farm-level interventions and within these different scales they must help farmers and rural communities to determine the timing, nature, and location of specific adaptive changes. The challenge lies in helping farmers and rural communities transition from current to anticipated future conditions, while keeping in sight the context of location-specific problems, appropriate scale and time frame, and availability of resources. To effect landscape-level changes in NRM, EAS providers will need to work with and through multi-stakeholder decision processes, help broker agreements, strengthen management structures, and mediate conflicts. There will be some hard choices to make.

Specific decisions related to climate change adaptation may include:

- When to switch to varieties and crops with greater tolerance to emergent climate change stressors
- When to modify or switch land-use systems (e.g., from annual crops to perennials more tolerant of droughts and intensive rainfall)
- When to transition from rain-fed production to supplementary irrigation as the frequency and length of dry spells increase
- When to augment and increase the capacity of drainage systems to handle extreme rainfall events
- When to shift use of land types – for example, moving from drought-prone uplands to better watered lowlands or moving out of increasingly flood-prone riparian areas
- When to diversify out of agriculture and ultimately abandon certain areas as they become untenable as zones of production

Making these choices for specific locations and at different scales will be difficult. The optimal timing for adaptive responses is never obvious, as it depends on local and external resources and costs; individual, social, and institutional capabilities; evolving markets; and national policy frameworks. Individual technology and management choices offer benefits under specific ranges of conditions and are suboptimal in others. Once taken, some choices may preclude following other action pathways. Some options involve significant lead times – e.g., for irrigation system development – that must be anticipated if they are to deliver full benefits as needs arise. Different choices offer varying degrees of robustness in their ability to meet a range of possible climate futures. And in all cases, there are limits to adaptation.

EAS Key Challenge No. 2: Enhancing Effective Technology Exchange, Adaptation, and Dissemination

EAS providers must enhance and facilitate technology exchange, adaptation, and dissemination to match the need for continual climate change adjustments. For guidance, EAS providers can learn from past and present examples of how others have adapted to significant changes in under climatic conditions, including indigenous responses, as well as draw lessons from formal research efforts relating to new or best-bet responses relevant to projected conditions. The ability to skillfully identify and efficiently assess, modify, test, and exchange useful technologies and practices from around the world will be increasingly important in adapting to climate change impacts as research systems struggle to keep pace with new and evolving problems (e.g., Ramírez-Villegas et al. 2011). One immediate challenge is the lack of a unified global agricultural knowledge system, leaving us collectively ill-prepared to rapidly draw upon and utilize the wealth of agricultural knowledge that has been generated over the course of human history.

EAS Providers: Bringing It All Together

It will be imperative for EAS providers to step more fully into a facilitating role. The EAS tools and tested practices to help farmers assess and implement climate change-related adaptations, necessary to maintain viable agriculture-based livelihoods, are early in their development. Moreover, while responding to the risks and impacts of climate change, traditional concerns for poverty reduction, economic growth, and food security cannot be abandoned. Fortunately, because of the close coupling of human and natural systems within agriculture, there are potential synergies between the various objectives; many adaptive measures can be viewed as "no risk" or "no regrets" (Heltberg et al. 2009) – i.e., changes that will strengthen overall resilience and enhance productivity regardless of when and whether anticipated climate-induced shocks materialize or not, for example, building up soil organic matter, maintaining year-round vegetative and/or residue cover, and investing in improved water-harvesting and conserving practices in dry areas.

The challenges of climate change call for stronger integration of NRM and agricultural EAS (Hunt et al. 2011; Johnson et al. 2006; Swanson 2008). However, few public-sector extension systems are structured to facilitate close integration of these efforts. There are exceptions, such as Malawi, where the same public-sector extension field agents support the full range of crop, livestock, fisheries, forestry, and irrigation programs. Having a single point of entry at the community level offers the potential of coordination between various initiatives. The downside, however, is that the demands placed on individual field agents to be knowledgeable across the entire spectrum of agricultural activities far exceed their training and the programmatic support they are offered (Simpson et al. 2012); this can lead to the overloading of frontline workers and confusion at the field level.

Closer functional linkages will also need to be (re)established between EAS and research programs, currently missing from most extension programs. Closer relations will allow EAS programs to benefit fully from research contributions, while research programs will benefit from a clearer understanding of the needs, challenges, and progress made by farming communities in adapting to climate change.

The management of local opinion regarding adaptation to the *new normal* will likely also become part of the EAS portfolio. Escalating conflict, avoiding panic and destructive short-term behaviors, as well as addressing the despondency of indigenous populations losing a sense of *place* are real concerns. Engendering trust and credibility with local populations will be key.

All in all, the levels of knowledge and skills required by frontline EAS providers to match various opportunities with site-specific needs, as well as EAS program flexibility and responsiveness, surpass any that are currently in place, yet define the path forward in preparing for life under the *new normal*.

The Road Ahead

The approximately 2.5 billion smallholder farmers (IFAD 2013) who manage a majority of the nearly 22.2 million square kilometers of the earth's surface under agriculture (Zomer et al. 2009) represent a tremendous force in our ability to utilize NRM practices to help mitigate the negative impacts of future climate change, and they form a large part of the target domain for EAS programming. Using agriculture as an engine for economic growth, poverty reduction, increased food security, and now also for adaptation to climate change is predicated on effecting widespread behavioral change involving the adoption of more productive, less wasteful agricultural technologies and management practices. But working on these themes with farmers and the rural poor under the *new normal* – in a context of continual and increasingly disruptive change – is a daunting new challenge. To effect behavioral change, EAS providers will first need to address the issue of helping farming populations understand that the *new normal* really is a departure from the past and that responding to it will require adoption of truly adaptive measures and not simply belt tightening and coping until conditions return to the way they used to be.

To respond to the breadth of challenges of adapting to climate change, EAS providers will need to (i) reconsider their strategies and operational frameworks for engaging rural populations, (ii) increasingly work with groups at appropriate scales, (iii) overhaul training curricula, (iv) maximize use of advanced information and communications technology (ICT), and (v) advocate for supportive policies. The remainder of the chapter addresses each of these issues in turn.

Evolving Strategies and Frameworks

The systemic nature of global climate change will require use of commensurate systems thinking to proactively engage the quadruple climate change challenge of mitigation, adaptation, decreased vulnerability, and increased resilience within the agricultural sector. The abandonment of support for the farming systems research and extension (FSR/E) paradigm by donors in the early 1990s has regrettably been accompanied by a nearly complete loss of formal systems analysis in applied agricultural research and extension practice. The payment for environmental services (PES) framework offers a conceptually rich subset of value chain development activity but has encountered stiff challenges in bringing *environmental externalities* into the marketplace. Watershed management and the *wild west* environment of the carbon-offset markets are probably the two PES action areas most relevant to EAS climate change efforts. Transaction costs and, in the case of carbon offsets, the costs of measurement, reporting, and verification systems have been barriers to widespread smallholder involvement.

One can hope that we are in a transitional phase and that more holistic climate change vulnerability assessment and adaptation planning procedures will become central features in development efforts. Given the nature and breadth of changes that are taking place under the *new normal*, it is difficult to envision how appropriate responses will be forthcoming without engaging in systems thinking and consideration of interactions.

Under the *new normal*, systems thinking will need to engage more broad-based system principles that hold over a wider range of conditions and recognize that the process of continuous change will not allow exhaustive investigations of individual, location-specific, system interactions. For example, precise recommendations on optimal intercropping associations (e.g., spacing, plant populations and planting patterns) will quickly become irrelevant with any significant change in rainfall or temperature, whereas basic principles relating to soil organic matter management, protection of critical water sources, and competitive and facilitative plant interactions can be applied by farmers in endless configurations across a range of climate regimes (e.g., Altieri 1987; Francis 1986; Gliessman 1990; Vandermeer 1989). Fortunately, within the domain of NRM-oriented agriculture, many land management principles confer broad-based, system-level benefits that allow farmers to contribute simultaneously to mitigation efforts while making needed adaptive responses and enhancing the resilience and profitability of their farming systems.

In the context of the *new normal*, the greatest advantage of the formal research system is the capacity to engage in anticipatory analysis, development, and dissemination of responsive technologies – for example, the development of new heat- and drought-tolerant maize varieties and the development of submergence-tolerant rice varieties by the international agricultural research centers (Cairns et al. 2013; Septiningsih et al. 2009). In contrast, formal research and EAS processes will likely prove too slow in responding to the real-time and disparate needs for more nuanced management adjustments by farmers in specific contexts. Continued practice of promoting prescriptive, general recommendations focusing on short-term optimization will become increasingly ineffective. The need to rely on and feed farmers' inherent adaptive capacities to fit tools and practices to local applications, the focus of much effort in the 1980s and 1990s in developing participatory methodologies, will need to be an integral part of EAS operational strategies.

Working with People

Regardless of the source of innovations, most EAS providers will need to engage in iterative cycles of experimentation and learning as they begin to work with rural communities in testing high-potential adaptation practices, preferably while risks are low. Consistent, ongoing EAS support in NRM-centric agriculture will be critical to give communities the confidence and skills to implement effective mitigation and adaptation efforts. Most technical options will require capacity strengthening and the support of broad-based community engagement.

In spite of the challenges, the nature of climate change impacts is such that strengthening social capital for collective action and strengthening the local knowledge base on local ecosystem functioning are essential parts of an adaptation strategy. In general, communities have a deep attachment to the areas where they live. Their collective history of environmental knowledge provides them with important assets for managing local natural resources. The shared knowledge and relationships of trust with one another and known points of opposition are the foundation for establishing effective comanagement structures, especially if they are fortified by strong community organizations, technical support for sustainable resource use, and policies codifying local resource rights (Brunckhorst 2010). Ferse et al. (2010) found that community involvement in environmental design for access, use, and protection of natural resources resulted in more adaptive, flexible management and more resilient ecosystems. Furthermore, when social networks included a mix of actors in the same watershed, those actors who had links to additional sources of information were able to bring new perspectives and opportunities that helped to improve management responses (Bodin et al. 2006).

EAS Education and Training

To help prepare EAS practitioners for the challenges described in this chapter, preservice education programs will need a major overhaul, and a process of regular in-service updates will need to be established. Recently, the importance of investing in tertiary (college-level) agricultural education has come back on the development agenda. But given the past neglect, needs vastly exceed the available resources and must be redressed if we are to begin taking the worldwide human resource crisis in agriculture seriously. One of the common findings of recent EAS assessments is the aging population of public-sector EAS staff; on average the members are within a decade of retirement (e.g., Simpson and Dembele 2011; Simpson et al. 2012; Simpson and Singh 2013). The gaps that will be created by retirement, combined with the current gaps and weaknesses in the EAS education and training system, will exert themselves for years to come, just as the pressures for a more capable EAS workforce are making themselves felt. Though particularly acute in Africa (e.g., Eicher 2004), the neglect of human resource development is by no means an African crisis alone (BIFAD 2003). There is now an opportunity to address this underinvestment in education by revitalizing national training programs to prepare the next generation of EAS practitioners for the challenges of responding to conditions under the *new normal*.

Information and Communications Technology (ICT)

The potential contributions of technological innovations to support sustainable development efforts have been promoted for over a decade (NRC 2002). Outside of the research community, however, little progress has been made. In contrast, the Famine Early Warning System Network (FEWS NET), one of the longest-lived programs involving applied advanced technologies, will likely see increased use in the decades ahead. To help capture the geographic and temporal dimensions of climate change impacts, climate and crop models, remote sensing, and geographic information system (GIS) technologies all have important roles to play in assisting policy-makers and research and extension program managers in targeting their respective efforts.

One example of combining the predictive capability of climate and crop modeling with soil and geographic data is the collaborative work undertaken by Catholic Relief Services, the International Center for Tropical Agriculture (CIAT), and the International Center for Maize and Wheat Improvement (CIMMYT) in Central America in the “Tortillas on the Roaster” project (Eitzinger et al. 2012). Developing an integrated assessment framework led to the identification of three major types of interventions and the ability to target these to specific geographic locations (see Box 3). One of the outcomes of this project was the capability to predict the effect of climate change on Central American maize and bean production in particular locations based on soil quality. This type of information can be immensely valuable in geographic and technical targeting of EAS programming.

Other ICT tools are equally valuable. Weather information and the use of radio and text messaging services have the potential to assist farmers in accessing real-time information for intra-seasonal management decisions. Early warning systems, such as FEWS NET (USAID) and the United Nations Food and Agriculture Organization Global Information Early Warning System, will become increasingly valuable tools for national decision-makers, donors, and emergency response agencies in gaining the lead time necessary to prepare response measures for slow-onset emergencies. For populations at risk, warning systems focused on rapid-onset emergencies, such as floods and typhoons, are in place and under development in South and Southeast Asia. In combination, the analytic power, communication reach, and immediacy of these ICT tools will become increasingly important for EAS programs.

Box 3: Three Major Types of Interventions Identified by the “Tortillas on the Roaster” Project

Adaptation spots: Areas where yield reductions of the crops in the model, in this case maize and beans, are expected to be 25 % and 50 % by the 2020s and 2050s, respectively. In adaptation spots, EAS for agriculture can be used to *promote locally appropriate adaptation practices*.

Hot spots: Areas where yield reductions of the crops in the model are expected to be >50 % by the 2050s. In hot spots, EAS would support *diversification of livelihoods and transitioning out of current, vulnerable livelihood systems*.

Pressure spots: Areas with potential for ≥25 % gains in production. The problem is that most of these pressure spots are forested or protected areas at risk of incursion by agriculture. Pressure spot interventions require support from EAS for *natural resource protection and sustainable management* and offer potential targets for PES (payment for environmental services) interventions (Fig. 4).

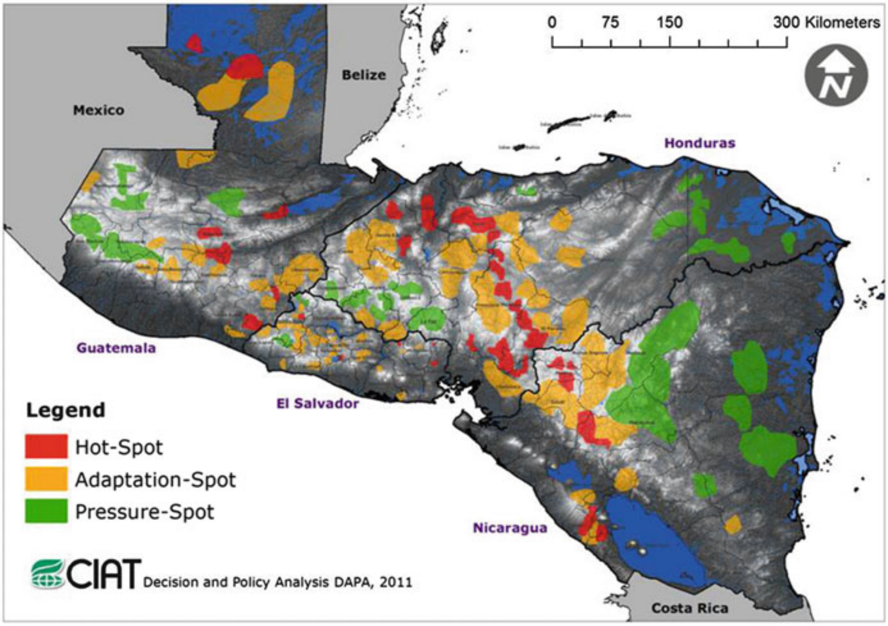

Fig. 4 Climate change impact on bean-producing areas in Central America

Importance of Policies

Few national EAS programs have launched initiatives aimed specifically at assisting farmers in adapting to climate change. The reasons for this warrant further investigation. At the policy level, however, there are growing indications of positive changes within national agricultural investment plans toward large-scale climate change adaptations. The *Plan Maroc Vert* (the Moroccan Green Plan) is one such example. Cast in terms of an economic growth and poverty reduction strategy, the Plan responds to a steady 30-year decline in rainfall levels by, among other things, assisting smallholder producers to transition from hillside annual crop production to higher value tree crop production, especially olives, almonds, and figs, which are tolerant of increasingly arid conditions. Accompanied by investments in structures to prevent soil erosion, these plantations will help farmers maintain and improve their livelihoods in the face of environmental change. The US$ 300 million investment under the US Millennium Challenge Corporation Moroccan compact, supporting the establishment and rehabilitation of 120,000 ha of hillside agroforestry plantations, is one of the first major investments in implementing *Plan Maroc Vert*, to which other donors are also contributing (Cooper et al. 2013).

Another example is the Malawi Greenbelt Initiative, with an initial target of bringing one million hectares under irrigation and strategic plans for developing 228,000 ha (Government of Malawi 2010). The initiative is primarily justified as an economic development effort aimed at exploiting surface water resources to increase high-value agricultural production and strengthen food security. The initiative stands to make major strides in assisting producers to transition to systems less exposed to the immediate risks of climate change.

These examples illustrate the type of policy decisions and the level of investments that governments must make in preparing for anticipated climate change impacts. Investments in EAS training programs and other support services are also needed to maximize benefits. To support implementation of *Plan Maroc Vert*, the Moroccan government has drafted a new national extension strategy. The Malawi Greenbelt Initiative called for the training of an additional 1,000 extension agents, with plans for hiring an additional 400 staff members over 4 years (Government of Malawi 2010). The sheer size of these undertakings and the need to mobilize resources are such that planning horizons must be lengthened to investment cycles of 10–15 years or more.

Agricultural policies involving subsidies are designed to influence farmer behavior in securing national food security objectives. These policies, however, can work against extension efforts to assist farmers to transition to more diverse, resilient production systems, leaving farmers more vulnerable to climate change trends and shocks (e.g., Simpson et al. 2012; Chinsinga et al. 2011). Decision-makers will need to review their policy frameworks closely with an eye to climate change adaptation to eliminate inconsistencies and identify leverage points.

Policy changes can also have dramatic effects in terms of facilitating farmer investments in NRM. For example, Niger's new Forest Code in 2004 recognized customary resource rights and the right to collect and use forest products. The granting of secure tenure rights, removal of punitive fines, and addition of a new source of technical assistance resulted in one of the most dramatic transformations of land cover in the region, with five million hectares, nearly half of the country's agricultural land, being converted to agroforestry management systems in less than a decade (Stickler 2012). In the process, farmers greatly increased their resilience to climate change impacts.

Best Prospects: Extension and Advisory Services Under the *New Normal*

The future of agriculture under the *new normal* is defined by increasing risks and uncertainties. The ideas presented here are by no means exhaustive, but are intended to focus attention on key issues, stimulate thinking, identify directions, and urge action at the appropriate pace and scale. There is an urgent need to make progress in climate change mitigation, preparing for adaptation, and to decrease vulnerability and increase resilience within the agricultural sector.

Recommendations for EAS providers:

1. EAS programs need to identify and be well informed about the essential nature of climate change risks and impacts, including the geographic zones of impact and likely trajectories of onset, the relative magnitude, level of certainty, likely timing, and location of slow- and rapid-onset risks.
2. Within the target locations for various types of risk, EAS providers must assess the vulnerability and resilience of human populations and natural resource systems in order to prioritize the allocation of resources. Use of a systems approach to identify linkages – involving at a minimum human/social, climate/environmental, financial/food security dimensions – is critical.
3. Based on assessed needs, EAS programs must identify any available multi-win, no-regrets, and robust options and demand that research institutions begin the hard work of assessing and screening available technologies for their fit under likely future conditions and identify technology gaps now so that appropriate responses will be available when needed. Issues that need to be taken into account by EAS programs include how to:
   (a) Match appropriate actions at the requisite scales and locations and plan for the temporal sequencing of responses
   (b) Determine social and organizational requirements to support technical choices
   (c) Develop market and nonmarket incentives for farmers and other stakeholders to stimulate behavior change
   (d) Mediate potential policy distortions that may increase smallholder risk
4. To identify potential technical and social alternatives, EAS providers must establish and aggressively engage in national and subregional platforms for networking and exchange of experiences and become skilled in tapping into

cross-regional and global resources. At the field level, learning from and building upon indigenous responses will be vital.

5. Technology transfer efforts need to be accompanied by streamlined procedures for technology release combined with the freedom to actively encourage and facilitate experimentation with new technologies by farmer groups.
6. EAS providers should participate in the identification and use of ICT applications (e.g., early warning systems) for various target audiences.
7. EAS education and training programs must be significantly upgraded so that field and management staff members are prepared for the risks of climate change. Critical areas include a sound understanding of climate change dynamics, a broad systems orientation, technical competency, and methodological expertise.
8. EAS program directors will need to engage more intensively in policy formation and review, with a view to incorporating plans for climate change adaptation and providing support for producer populations that may be at risk. Policy-makers must prioritize investments in EAS programs and related support services to help farmers make difficult transitions.
9. Programmatic divides between ministries must be identified and removed, in order to capitalize on potential operational synergies among EAS programs (e.g., crops, forestry, livestock, etc.). National EAS programs must also actively seek collaboration with actors outside of government who can help to increase the scale of impacts of EAS efforts.
10. Perhaps most challenging of all will be efforts to bring field-level coordination and coherence to public- and donor-funded initiatives and to help orient private-sector actors to emerging climate change adaptive opportunities. Design and implementation of national strategies should involve coalitions of public- and private-sector actors with donors and NGOs.

The list of needs is long and the demands are high, but the stakes are higher still. All those involved will be challenged to elevate their efforts. Our continued ability to feed the planet depends on the outcome.

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Agriculture and Climate Change in Southeast Asia and the Middle East: Breeding, Climate Change Adaptation, Agronomy, and Water Security

Ijaz Rasool Noorka and J. S. (Pat) Heslop-Harrison

Contents

Abstract

The agriculture of Southeast Asia and the Middle East is under threat due to vagaries of abiotic stress including climate change and water-related factors. With a particular focus on the challenges facing non-industrialized and developing countries, this paper attempts to create a framework for policy makers and planning commissions as well as increasing national and regional water stress awareness. The study elaborates the agriculture eminence, water provision, conventional water usage, and adverse consequences of water status under the changing climatic conditions and urban or industrial development. The study addresses the nature of problems, regional issues, current barriers, farmer's perceptions, and concrete efforts to save regional agriculture for sustainable food security. The consequences

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of climate change, water stress, and salinity have affected huge areas of developing countries from an economic and resource security perspective that leads to disaster and unstable law and order issues. Long-term planning over timescales beyond the human lifespan and anticipation of threats and opportunities is required. Consequently, an emergency plan is also needed for international, national, and regional footprints including procedures for climate change mitigation and to implement inclusive plans to combat prevailing poverty, social changes, and allied anticipated risks. It elaborates the attempts to provide a framework for policy makers and political understanding to check the hidden but viable issues relating risks of climate change in local and global scenario. It is concluded that a viable charter of climate proofing and domestication is the way to success from on-farm-to-lab and lab-to-field outreach to mitigate declining food issues. The regional and international collaborative efforts are focused to modernizing crop genetics, agronomy, field-to-fork scrutiny, and adaptation training to increase quantity and quality of food with sustainable use of water.

Keywords
Climate change • Irrigation scheduling • Quality food • Southeast Asia

Introduction

The agriculture of Southeast Asia and the Middle East is mainly dependent on rain and groundwater which is, with current crops and management practices, neither sufficient nor reliable to meet the requirements of the crops (Noorka and Afzal 2009). Due to this, crop production is under serious threat, and potentially for survival, given the vagaries of abiotic and biotic stress under the changing climatic conditions. The consequences of climate change, water stress, and salinity have not only affected huge areas but also health and socioeconomic issues throughout the world particularly in the developing countries, leading to severe poverty, shaken resources, food insecurity, internal and external security issues, and catastrophes. Under the burgeoning population pressure including increasing urbanization, and severe weather conditions, Southeast Asia and Middle East countries will suffer food shortage in the coming decades if the present momentum of climate change situation persists for longer time as it is predicted. So short- and long-term planning over timescales, according to the wishes and necessities of human lifespan, is needed.

Climate Change and Agriculture

Climate is considered as the average weather and variations in relevant quantities for a number of decades, centuries, or potentially years. According to the World Meteorological Organization, the classical periods lag for a long time with the surface variables like wind, rainfall, and prevailing temperature. Change in climatic conditions result from natural climatic variations, solar cycles, volcanic eruptions and atmospheric changes and have direct consequences on land and water inhabitants flora and fauna (Pahl-Whost 2007; O'Brien et al. 2008). The climate change commitment is simply an account of predicted future changes in shape of hydrological cycle, changes in sea level, and rise and fall in weather conditions with constant anthropogenic emissions. It is anticipated that climate change takes place over a few decades or less, which directly or inversely has the potential to provide substantial interferences in humans as well as in ecosystems (Kashyap 2004; New et al. 2007). The immediate action to combat climate change is adaptation, a process of larger and smaller changes required to anticipate expected outcomes of climatic effects, by exploiting beneficial opportunities and minimizing harmful effects. In our natural systems, the process of sectioned resources management by augmentation of applied and basic research is suggested to tackle the forthcoming climatic threats (Power et al. 2005; One World Sustainable Investments 2008). Climate change and agriculture are interrelating and dependent on each other (IPCC 2007). Climate proofing and domestication of plants have played significant role to counteract changes in climate over the 10,000 years of human agriculture and have the potential to meet the challenges of global warming which have significant impacts on agriculture by the interaction of various elements like rainfall, fluctuating temperature and carbon dioxide concentration, glacial runoff, etc. to ensure crop maximization (Challinor et al. 2009; Fischer et al. 2002).

Lobell et al. (2008) concluded that due to climate change, by 2030, Southern Africa may show 30 %yield loss of maize (*Zea mays*) crop, while in Southeast Asia is predicted 10 % yield loss in staple crops such as rice (*Oryza sativa*), maize, and millet (*Pennisetum glaucum*). It is a matter of grave importance that agricultural production will definitely be affected by the predominance and pace of climate change, if it will transpire step by step, but in contrast the rapid climate change will upset the present momentum of agriculture production in a lot of countries, exclusively having poor and degraded soil with hot weather and under drought condition (Ziervogel et al. 2010) (Fig. 1).

The optimum natural selection and adaption could lead to genetic erosion as well as nonconservation of genetic resources, so care must be taken to avoid such loss of valuable genetic resources. Thus, the affiliation in climate change and agriculture is in multiple ways confounded and contrasted: agriculture significantly contributes towards climate change, and climate change can detrimentally distress agriculture.

Adverse Consequences of Water Status Under Changing Climatic Conditions

Water, the necessity of life, has emerged as the top commodity of present and future time and shall remain on top of planning concerns for farmers, policy makers, and researchers (Noorka et al. 2013a). Frontline workers responsible for water management to combat water stress and occasional drought have been as well as seasonal climate forecasts support decision making to manage water resources and dam management (David et al. 2008; Noorka and Schwarzacher 2013). Drought is

Fig. 1 Shallow terracing seen here allows efficient use of water in rainfed agriculture while preserving soil and slowing runoff

considered as the complex natural hazard that causes corrosion of water resources by quantity and quality (Noorka and Teixeira da Silva 2012). Droughts have imposed a serious menace to agricultural production and development of socioeconomic activities in the semiarid and arid regions which are more susceptible to the effect of drought (Noorka et al. 2013b). Agricultural production in semiarid and arid regions is constrained by low rainfall, poor or low-nutrient soils, high temperatures, high solar radiation, and low precipitation, raising food insecurity. IPCC (2007) highlighted the large potential for biofuels to meet the growing energy needs as well as contributing to GHG emissions reduction and enhancement of carbon sequestration in soils and biomass (Fig. 2).

Agriculture in Southeast Asia and the Middle East

The agriculture of Southeast Asia and the Middle East is under threat due to ultimate vagaries of abiotic stress including climate change and water-related factors (Angus and Van Herwaarden 2001; Ahmad 2005), and it is expected that it will affect the agriculture by a series of steps, e.g., change in rainfall, extreme temperature, and water stress will open the doors of severe drought by direct and indirect ways. With the increase in temperature, some specific areas like the Philippines will lose its agriculture production, while Indonesia and Malaysia are projected to gain the rice yield. Resultantly the driving force in agriculture is

Fig. 2 Overgrazing and lack of terracing lead to low grassland productivity, soil erosion, and invasion by aggressive aliens (here, *Argemone mexicana*)

Fig. 3 Wheat trials exploiting diversity in the search for plants with efficient growth under rainfed conditions. Here, selections with and without awns are being trialled under low-input conditions

increasing the demand for food and fiber throughout the globe. With particular focus on the challenges facing developing countries, this paper attempts to create a framework for policy makers and planning commissions as well as increasing national and regional water stress awareness (Singh 2002) (Fig. 3).

The geographical situation in this area predicts that under the changing set of climatic situation up to 2050, most countries will become hotter, have less and un-reliable rainfall, and as a consequences sever reduction in agricultural production if the current policies, crops and genetic attributes are retained unchanged.

Agriculture Eminence

Agriculture is the social and economic core and main employer in many developing countries. Drought and its consequence of desertification with salinity and soil loss are expected to increase in the coming decades, with disastrous consequences from climate change (Moss and Dilling 2004; Hampel 2006). Droughts impose a serious threat to agricultural production and development of socioeconomic activities in the semiarid and arid regions by low rainfall, poor or low-nutrient soils, high temperatures, high solar radiation, and low precipitation. A viable charter of climate proofing and super-domestication through genetic improvement, in combination with optimized agronomy, is the way to success from on-farm to lab and lab to field outreach to mitigate declining crop productivity and food issues. The regional and international collaborative efforts are focused on research and experiments to modernize the crop genetics, agronomy, field-to-fork scrutiny, and adaptation training to increase quantity and quality of food with sustainable water harvest.

Current Barriers in Understanding

Introduction and problem identification of climate change is expected to make this seasonal distinction even stronger, with more frequent summer droughts coupled with increased winter rainfall and more floods. On-farm water storage of the higher winter flows is one of the main options for securing a more reliable water supply for irrigation. The media, the most effective weapon of present time, have to play a major role in converting the people's perception to portraying climate change (Hampel 2006). Sometimes, media reports create confusion using their own perception without considering the expertise and scrutiny of the scientific community (Moss and Dilling 2004). Water availability and its predicted more frequent shortage are important barriers for efficient crop productivity that vary from one spatial scale to another. Reckoning crop water productivity, it is determined that there is gap among policy makers, consultant, researcher, extensionist, agronomist, and farmers themselves to enjoy the full supply of crop water productivity. However, a big breakthrough was observed with the employment of molecular breeding, domestication, and climate proofing (Heslop-Harrison and Schwarzacher 2012).

Farmer's Perceptions

The farmers are the most beleaguered community of Southeast Asia and Middle East societies. The governmental policies to confront the negative image of climate change, food insecurity, middleman role in agricultural marketing, insufficient storage facilities, conventional agricultural production practices, lack of extension services, and technology transfer (Schulze 2000; Roux et al. 2006). The young people in the farming community are absconding towards the big cities in search of livelihood and ignoring their small landholdings. The old people, their forefathers, are unable to understand the latest technologies to employ in agriculture and to achieve the potential of the varieties. The media and agriculture department can play an important role to educate the farmers (Jury and Vaux 2005), while governmental healthy and farmer-friendly policies like timely announcement of support price of staple food as well as cash crops, farms to market road access, water provision, water stress tolerant varieties, and quality production.

Concrete Efforts to Save Regional Agriculture for Sustainable Food Security

Genetic resources are the vital source of crop production and food security across the borders (Von Bothmer et al. 1992; Skovmand et al. 1992). The range of genetic diversity within crops and their relatives is a precarious source for potential increase in crop production and for new sources of resistance and tolerance against biotic and abiotic stresses (Ahmad et al. 2010). The Food and Agriculture Organization of the United Nations (FAO), the Commission on Genetic Resources for Food and Agriculture, the International Plant Genetic Resources Institute (IPGRI), and the International Board of Plant Genetic Resources (IBPGR) have played an important role in the publication and preservation of germplasm (Skovmand et al. 1992). The International community has the obligation to aid agricultural research systems world-wide in the context of climate change to ensure world's food security and peace. Building a partnership for development is one of the United Nations' Millennium Development Goals.

Conclusions

The consequences of climate change, water stress, and salinity have affected huge areas of developing countries from an economic and resource security perspective, which leads to disaster and unstable law and order issues. Long-term planning – over timescales beyond the human lifespan – and anticipation of threats and opportunities are required. Consequently, an emergency plan is also needed for international, national, and regional footprints including procedures for climate change mitigation and to implement inclusive plans to combat prevailing poverty, social changes (including urbanization of populations and changes in diets), and allied anticipated risks. The researchers urge more climate proofing infrastructures, water scheduling, improved drainage, and water harvesting. The water resource management, use of treated wastewater, serious attempts to limit greenhouse gas emissions, societal impacts on climate change, and shortening/shifting the growing periods of crops will definitely help the researchers to cut down the negative impact of climate change. The study attempts to provide a framework for policy makers and political understanding to check the hidden but viable issues relating to risks of climate change in local and global scenarios.

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Approaches to Climate Change Adaptation of Vulnerable Coastal Communities of India

Chinmai Hemani

Contents

Abstract

In the context of developing countries, climate change and variability poses a serious threat to the coastal rural communities due to their poor adaptive capacities, weak implementation of developmental activities, and lack of technological solutions needed to address this challenge. In order to address the current vulnerabilities of these coastal communities where development initiatives are itself lacking, adaptation measures will play a crucial role in streamlining and collaborating with development initiatives. Literature review in Indian context suggests that there are no estimates available of

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impact of climate change on coastal agriculture and fisheries and therefore on agricultural, pastoral, and fishing communities. This research addresses the aforementioned research gap with a case study from Western India focusing on livelihood security and human well-being while integrating development plans to climate change adaptation. Based on vulnerabilities identified for the study areas, adaptation plan consisting of goals with several measures were created which were linked to existing national development schemes along with their co-benefits and barriers to implementation. Development choices made today will influence the adaptive capacity of people in the future. Thus, there is an urgent need to undertake development activities and decision making with climate lens, and this research will be the first step in the process.

Keywords
Mainstreaming climate change adaptation • Adaptation plan and options • National and state development plans • Millennium development goals

Introduction

First time in the human history, a record was set when global concentration of carbon dioxide (CO_2) measured at Mauna Lao lab crossed 400 parts per million (ppm) in May 2013 (National Geographic 2013). The rise in CO_2 levels is a result of an increase in anthropogenic greenhouse gas emissions (GHG) leading to increase in the global mean temperature. Climate change projections for 2100 suggest a best estimate of global average surface temperature to rise by 4 ºC (IPCC 2007). A 4 °C rise could be potentially devastating leading to inundation of coastal areas, increased intensity of tropical cyclones; unprecedented heat waves, exacerbated water scarcity; increasing risks for food production potentially leading to higher malnutrition rates; and irreversible loss of biodiversity (The World Bank 2012). Even if efforts are made to cap and mitigate the GHGs today, air and sea temperatures will continue to rise as a result of past emissions. Thus, mitigation efforts alone will not work; adaptation is also needed in order to tackle increasing impact of climate change.

Surrounded by Himalayas, with a coastline of 7,500 km and 70 million hectares of forest, India is one among 17 mega biodiverse countries in the world which is exposed to climate change on multiple grounds. No country in the world is as vulnerable on so many dimensions to climate change as India (INCCA 2010). Disasters caused due to increasing extreme events like the recent Uttarakhand floods in June 2013 left thousands dead while severely damaging the infrastructure illustrate super imposing effect of an extreme weather event accompanied by poor mitigation, adaptation, and disaster management practices. Depending on the level of preparation by local and national institutions to manage the hazard, an extreme event can turn into a disaster; thus, socioeconomic systems play a vital role in regulating climate change impacts.

India has nine densely populated coastal states comprising of 20 % of the entire population (INCCA 2010) with livelihood dependence on agriculture, fisheries, mining, petrochemical and other industries, ports, and various tourism centers. Increasing population and subsequent land use changes have led to environment degradation, biodiversity, and freshwater stresses which would increase many folds due to climate change.

Literature review in Indian context suggests that there are no estimates available of impact of climate change on coastal agriculture and fisheries and therefore on agricultural, pastoral, and fishing communities which are expected to be significant (Revi 2008).

This study attempts to address research gap mentioned above by studying vulnerabilities of coastal rural communities while addressing following research question:

- What national and state development plans and policies are appropriate for more adaptation friendly path in order to overcome the current vulnerabilities and whether they need to be leveraged to address future climate change?

In spite of planned development path, the development challenges in India are quite high with 29.8 % of population still living below poverty line (BPL) (Planning Commission of India 2012). With weak implementation of planned development, India is yet to curb the inequitable share of resources. Climate change is likely to exacerbate these inequalities in turn increasing their vulnerability, but if development goals are systematically considered and implemented by linking them with adaptation options, enormous cost reductions can be achieved while trying to address development and climate change challenges.

The complete research comprised of three stages: (1) identifying the problem (vulnerabilities), (2) exploring applicability of existing development policies and evolve inclusive adaptation options, and (3) reducing vulnerability by choosing adaptation options.

Support tools used for methodology to derive climate change adaptation options for this research are depicted in Table 1.

The Need to Rethink Our Current Approach

Humans over their evolution have been coping and adapting ex post to climatic variations. A new approach suggests adaptation measures ex ante by incorporating future climate risk into policy making. Integrating adaptation into development projects is an iterative process of incorporating considerations of climate change into policy making, budgeting, implementation, and monitoring processes at

Table 1 Research area and support tools used

Type of tool used	Current climate analysis	Information on future climate change scenarios used for future vulnerability	Climate change sector impacts	Analysis of adaptation options	Linking adaptation options to existing development plans and policies	Stakeholder analysis of options	Economic analysis of options
Primary surveys	✓	✓	✓ Partially as here focus is on livelihood and well-being	✓	✓	**x**	**x**
Focused Group Discussion (FGD)							
Key informant interviews							
Climate data analysis							
Secondary studies							
Multi-criteria analysis (MCA)							

Note: ✓ indicates task considered, **x** indicates task not considered for this research

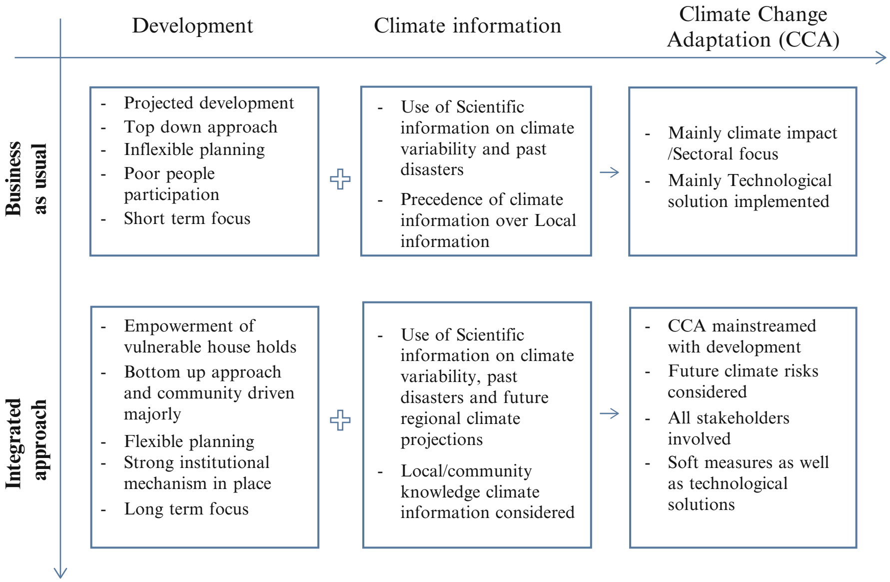

Fig. 1 Integrated approach for climate change adaptation (Source: Adapted from Faulkner (2012))

national, sectoral, and subnational levels which entails working with a range of government and nongovernmental actors (UNDP-UNEP 2011). Figure 1 depicts comparison of business as usual development approach to an integrated approach which addresses development and climate change adaptation issues.

For developing countries, where there is lack of basic infrastructure especially in the rural areas, increasing evidences of climate change impacts will increase the adaptation deficit unless adaptation program is incorporated into development initiatives. Such development projects would help build readiness in times of crises in context of proper shelter; food, water, and agriculture security; and livestock protection to the target population so as to ensure increased adaptive capacity and reduced impacts of climate hazards. Without focus on adaptation, climate change impacts would erode development gains and deepen the development divide between geographical regions (developed and developing) and sections of society which are marginalized, poor.

In order to reduce vulnerability, efforts need to be made in the direction of good policies at national and state level to be relayed into local-level action facilitated by the local actor (CARE International, July 2010). Figure 2 suggests a joint effort of public – civic and private – institutions for implementation and governance of adaptation measures needed to facilitate adaptation efforts.

For India to achieve its National Development Goals and the Millennium Development Goals (MDGs), development with climate change lens incorporating adaptation measures is a must.

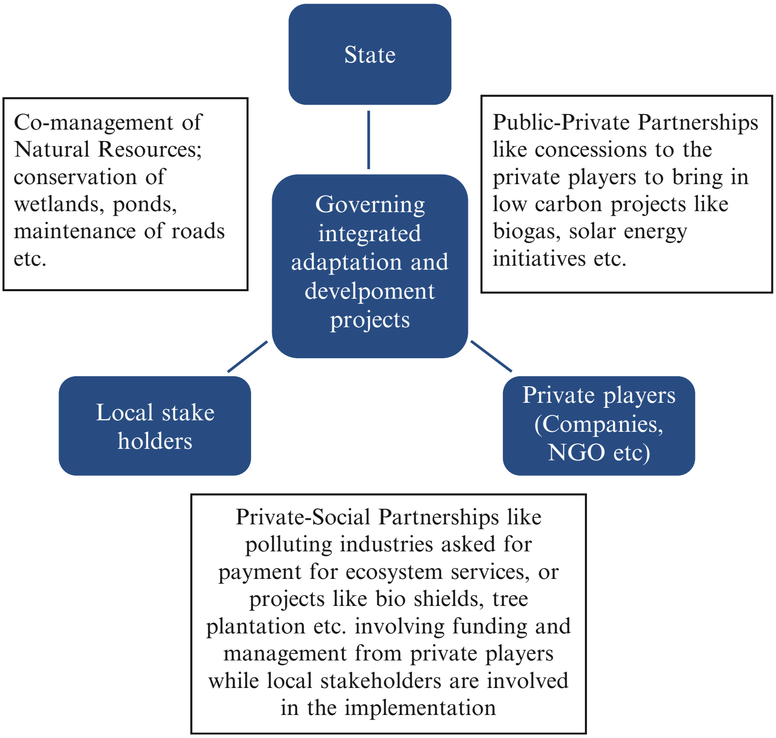

Fig. 2 Institutional arrangement for integrated adaptation action (Source: Adapted from Wreford et al. (2010))

Case Studies

Jamnagar district[1] lies between 21° 47′ and 22° 57′ north latitude and 68° 57′ and 70° 37′ west longitude in the state of Gujarat. It has a coastline of 355 km which accounts to 20 % of Gujarat's coastline with 3 coastal talukas.[2] Due to the presence of wetlands and bird sanctuary of Khijadiya, corals and Marine National Park (MNP) make Jamnagar taluka environmentally significant. Industrially, it has petrochemical special economic zones (SEZ) and many salt pan units; major brass part works along with two ports and two fishing centers. Socially also due to the presence of highest marginalized population with respect to other talukas in the district according to Census of India 2001, Jamnagar taluka was chosen for study. Four out of twelve coastal villages falling within 0–5 km from coast were chosen to understand the vulnerability of the coastal rural communities.

[1]District: administrative division within a state managed by local government

[2]Taluka: a smaller administrative division within district

They are unique in selection and are a representation of a class of such villages which have fishing/agriculture/mining or ecosystem dominance. Village demographics is presented in Table 2 and Fig. 3.

In order to understand the current vulnerabilities of these villages' to climate change, various questions were sought under vulnerability assessment, viz., what were the major impacts of past disasters, which group of population is most vulnerable to these disasters and why? What is the adaptive capacity of these villages and what measures needs to be developed such that adaptive capacity helps in reducing vulnerability and thus adapt to the changing climate, what barriers are there to the implementation of these measures? Reducing vulnerability thus becomes basis of adapting against climate change.

Next section briefly explains how vulnerability assessment was done for the study villages.

Climate Change Vulnerability Assessment Framework Used

Three factors, viz., extent of exposure to climate change, vulnerability of the region/community to climate change, and adaptation measures carried out, will define how regions and sectors will be impacted by future climate change (IPCC 2001).

Vulnerability assessment involves analysis of current exposure to climate shocks and stresses and model-based analysis of future climate impacts on basis of which adaptation strategies can be made. There are many conceptual frameworks to conduct vulnerability assessment, but many focus on any one stressor like drought, earthquakes, or tsunamis; multi-stressor vulnerability assessments while more difficult are slowly emerging (Adger et al. 2007). A thorough vulnerability assessment can be complex and intensively dependent on data.

Data and Methods

A vulnerability assessment framework as suggested by Hemani (2013) is a bottom-up approach which focuses on temporal reference as current, with vulnerable system as coastal villages, and the valued attribute as livelihood security and human well-being. It suggests how regional downscaled climate data can be integrated with the social vulnerability assessment and environment vulnerability to make overall vulnerability of the study region.

Climate information is one of the several factors that are needed to be taken into account in decision making. It also requires understanding of how regional scale climate variability leads to local manifestations and sectoral consequences.

In this study physical vulnerability consisted of scientific analysis of climate data of temperature and rainfall along with past trends of droughts, storms, and SLR based on secondary data.

Table 2 Village demographics

Parameter	Criteria	Villages			
		Rasulnagar	Khijadiya	Khara Beraja	Dhinchada
Socio Demographic data : 2001 Census*	Population	1364#	2,560*	537*	2,790*
	Area in hectare*	Not available	1,076	846	1,235
	Un-irrigated area in hectare*	Not applicable	409	379	560
Physical	Distance from coast (km)	1	5	3	3
	Distance from the city (km)	20	12	9	6
Infrastructure presence	Piped water	No (only 6 hand pumps for water needs)	Yes (but salt pan workers colony does not have water access)	Yes	Yes
	Irrigation and water storage	No	Yes (irrigation canal, water tank, check dams, farm ponds, ongoing construction of canal for salinity ingress prevention)	Bore well as well as hand pumps, water tank	Water tank and bore
	Primary school	Yes	Yes	Yes	Yes
	Presence of primary healthcare center	No	Yes	No	No
	Private/ public transportation	Private	Majorly private (only one public bus comes throughout the day)	Private	Private
Social	Dominant class[a]	Muslim	Hindu – Patel	Hindu – Harijan and Bharwad	Hindu – Satwara
	Major occupation	Fishermen	Agriculture, farm labor and cattle rearing, presence of salt pans	Majority – labor, some farming	Agriculture, cattle rearing, laborers and farm laborer, brass parts works
Environment	Presence of wetlands	No	Yes	No	No

(*continued*)

Table 2 (continued)

Parameter	Criteria	Villages			
		Rasulnagar	Khijadiya	Khara Beraja	Dhinchada
Remarks			Declared bird sanctuary 170 migratory birds 15 globally rare and threatened (CCF 2012). Existing salt pan workers colony is in low-lying area and lacks basic infrastructure		Village is in proximity to Jamnagar city; in future the village is likely to be merged with the expanding city

[a]Dominant class: small group of people of particular caste, with most political power
*Info. from data collected by Village head in 2011

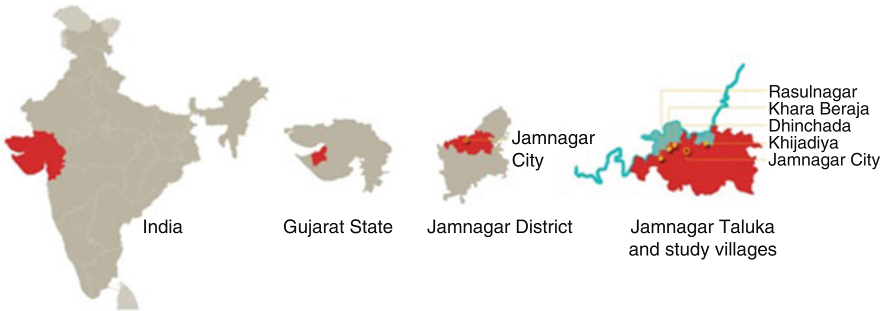

Fig. 3 Maps showing location of case study villages

10-year moving average analysis of 40 years temperature data from 1960 to 2009 of Jamnagar weather station reveals an increase in mean surface temperature by 0.72 ºC. Numbers of heat waves have increased and the winter has shortened. While future temperature projections for 30-year period between 2070 and 2100 were analyzed by Taru (2010), using downscaled regional model (PRECIS) (developed by Hadley Research Center in collaboration with Indian Institute of Tropical Meteorology) for Emission scenarios A2 and B2 suggests that average annual minimum temperature may increase by 3.7 ºC and 2.7 ºC as per the A2 and B2 scenario, respectively. Increasing trend of temperature and future projections indicate a high level of vulnerability.

For rainfall, 30-year moving average analysis for Jamnagar weather station from 1901 to 2011 for monsoon months (June to August) suggests that there is a steady increase of 0.66 cm per year in the rainfall over the 11 decades on an average. While future climate change projections for rainfall study done by Taru (2010) suggest that there would be moderate increase in rainfall, increase in number of dry spells with increase in extreme precipitation single-day events exceeding 100 mm reaching 14 each in A2 and B2 scenario between 2070 and 2100 for Jamnagar district. Decreasing number of wet days and increasing rainfall trends and future projections indicate high level of vulnerability. A detailed analysis covered by Hemani (2013) categorizes level of physical vulnerability into high, medium, and low for various climate variables like temperature, rainfall, sea level rise, cyclones, and storm surges based on the past trends and the future climate projections by Taru (2010).

Environment vulnerability of villages was made based on the presence of biodiversity, the characteristics of geology of that area, and availability and quality of water sources. A detailed analysis covered by Hemani (2013) categorizes environment vulnerability into high, medium, and low level depending on the deviation of the indicator value from the designated standards which were obtained from secondary data sources available at Gujarat Ecology Commission (GEC), MNP, etc.

Social vulnerability assessment used primary data obtained through different tools like FGD, transect walks, personal interviews, and key informant interviews. LVI-IPCC (Livelihood Vulnerability index) Indexing method as suggested by (Hahn et al. 2009) was found most appropriate and was applied for the assessment. Indicators chosen were based on extensive literature review and were categorized according to IPCC definition of vulnerability into those that define exposure, sensitivity, and adaptive capacity. While some indicators were based on Hahn et al. (2009), Mohan and Sinha (2011), and Vincent (2004), others were created due to necessity based on the field observations. Most of the indicator values were derived from the field surveys while values for some were derived from secondary sources. Table 3 suggests the list of indicators and major components used for the social vulnerability assessment.

The outcome of the assessment is depicted in Figs. 4 and 5. Figure 4 suggests villages performance on each of the major components mentioned in Table 3. Vulnerability of each village ranged from −1 to +1 where −1 indicated least vulnerable and +1 indicated most vulnerable. Figure 5 suggests Rasulnagar being the most vulnerable and Dhinchada being least vulnerable of the four study villages.

Social vulnerability assessment helped ascertain the dimensions of current vulnerability and the underlying causes for the same. It also led to understanding as to how does community cope and adapt to it currently, who are the stakeholders.

An overall vulnerability profile for each village was made by combining physical, environment, and social vulnerability as depicted in Figs. 5 and 6 through, e.g., of Rasulnagar village (Fig. 7).

A full analysis and the corresponding charts of vulnerability are covered by Hemani (2013).

Main Findings from Vulnerability Assessment

Based on the overall vulnerability of all the study villages, the concerns of the fishing and nonfishing villages are consolidated and summarized in Table 4 below:

Table 3 Social vulnerability indicators

Major component	Indicators
Sociodemographic	Dependency ratio, sex ratio (inverse), % of household (HH) where head of the HH has not attended the school
Economic well-being	% of HH that borrow money, % of HH that live in semipermanent house, % of HH without vehicle, % of HH below poverty line, % of HH having at least one vehicle (inverse), access to information services (telephone connections – wireless, wireline, TV, radio) (inverse)
Livelihood	% of HH with family member working in different community, % of HH into agriculture/fishing, average agriculture/fishing livelihood diversification index
Health	Average time to health facility, % of HH with family member with chronic illness, % of HH with no sanitation facility
Food	% of HH dependent on family farm for food, average months the HH store food, % of HH that do not save seeds from each harvest, average crop diversity index
Water	% of HH reporting water conflict, % of HH that utilize natural water source, average time to water source, % of HH that do not have consistent water supply, average number of liters of water storage
Natural resource dependence for fuel wood needs	% of HH dependent on natural resources for fuel wood
Institutional stability and strength of public infrastructure	Presence of unmetaled road, % of HH that travel out for medical treatment
Biophysical	Distance from coast/river/reclamation bund, distance from the major city, un-irrigated area, salinity intrusion, presence of wetland
Natural disasters and climatic variability	Average no. of floods/droughts/cyclones events faced in the past, % of HH that did not receive warning about pending natural disaster, % of HH that reported death or injury of family member of past natural disasters, mean maximum and minimum monthly average deviation temperature by year, and average deviation of monthly rainfall of rainy season

Source: Hemani (2013)

While the findings of the assessment suggests, it is the poor who are disproportionately affected, few crosscutting issues which add to the vulnerability across all strata and across all the study villages were categorized into following on basis of which adaptation goals were created:

Institutional barriers consisting of lack of:

– Institution setup like primary healthcare centers, banking facilities/credit societies
– Infrastructure like metaled roads, piped and dependable water supply, drainage network, conveyance facilities, and sanitation facilities
– Solid waste management
– Communication facilities like that of weather forecast systems

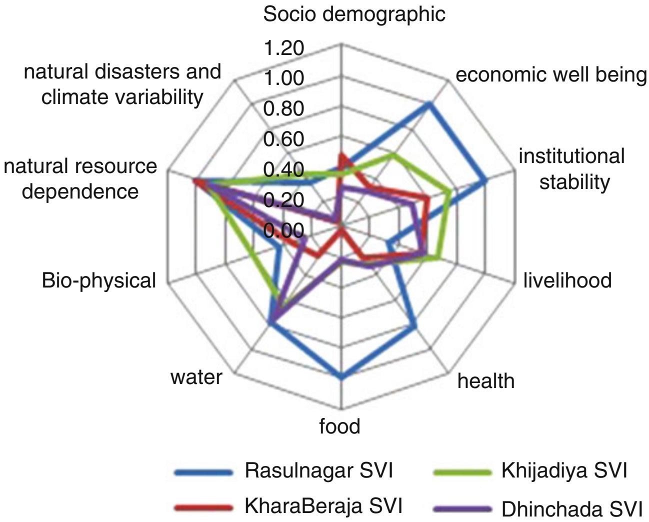

Fig. 4 Highlighting major component issues of study villages (Source: Hemani (2013))

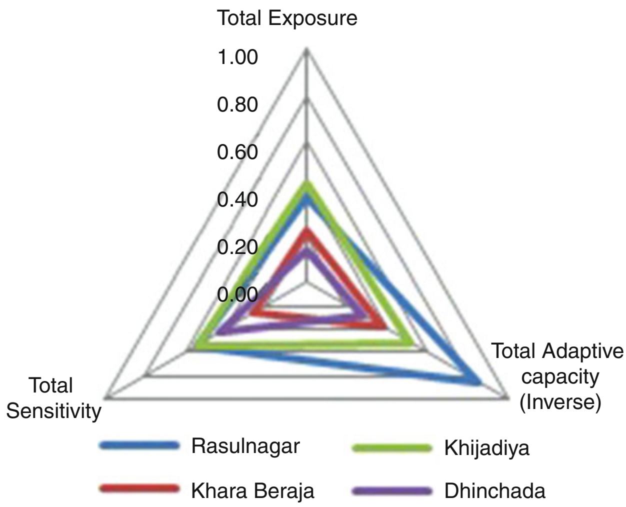

Fig. 5 Vulnerability of study villages (Source: Hemani (2013))

Financial barriers:

– Lack of funding

Technical barriers consisting of lack of:

– Education level and hence lack of alternative livelihoods
– Awareness on climate change and its impacts

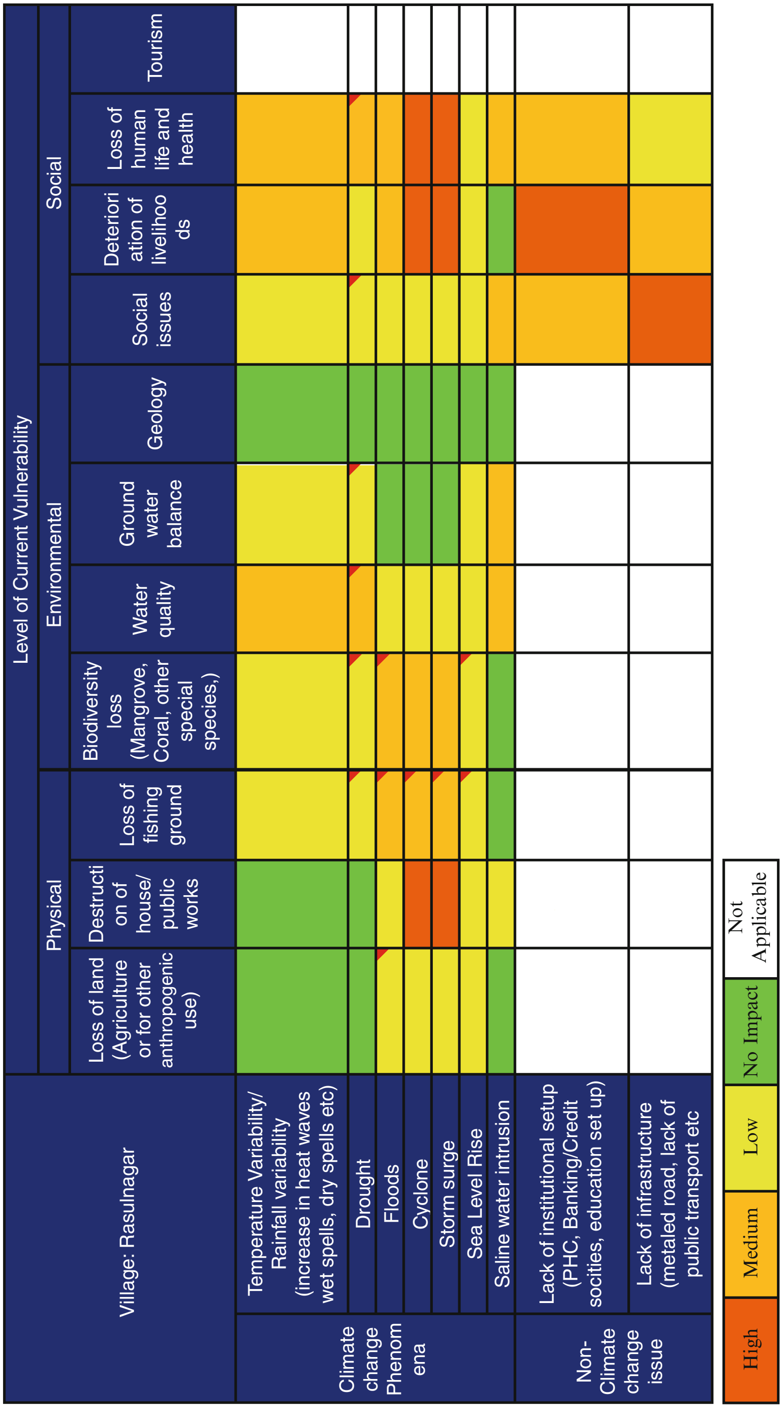

Fig. 6 Current vulnerability (Source: Hemani (2013))

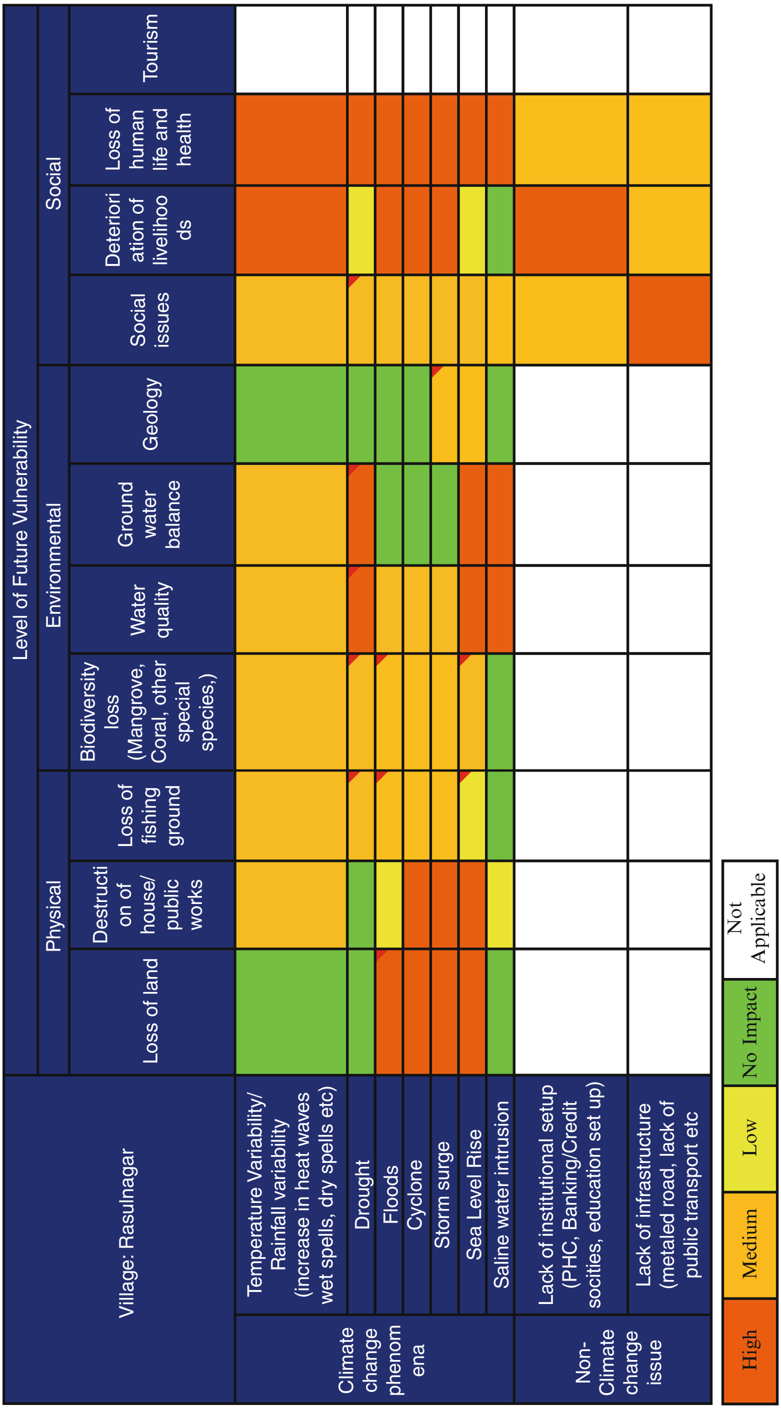

Fig. 7 Future vulnerability (Source: Hemani (2013))

Table 4 Vulnerability assessment findings

Aspect of vulnerability	Impacts	Agricultural/mining village concerns	Fishing village concerns
Physical	Loss of land	Future climate event concerns leading to loss of land due to floods, SLR, etc.	
	Destruction of house and public works	Lack of proper infrastructure, lack of adaptive capacity	
	Loss of fishing ground		Climatic concerns, wrong fishing practices, chemical industry presence, leading to loss of livelihood
Environmental	Loss of biodiversity/ wetland	Lack of awareness of the importance of biodiversity, climate change leading to loss of biodiversity	
	Change in water quality	Over extraction practices leading to salinity ingress, future climate change concern	Lack of proper infrastructure for freshwater resources
	Change in ground water balance	Over extraction practices and minimal ground water recharge, future climate change concern	
	Change in geology	Future SLR, salinity intrusion in agriculture driven villages, mining basalt trap rocks in mining villages will change the geology and make them more vulnerable	SLR will lead to inundation
Social	Increase in social issues	Lack of education and women empowerment, inequality	
	Deterioration of livelihoods	Loss of land due to salinity ingress leading to deterioration of livelihood, alternate source of livelihood needed	Presence of chemical industry, port activities affecting fishing, and hence deterioration of livelihood. Future climatic changes
	Loss of human life and health	Lack of medical facilities, lack emergency warning systems	
	Loss of tourism	Lack of awareness of value of wetlands, birds, and other important species at Khijadiya sanctuary	Lack of awareness of corals, sea grasses, dugongs, and other important species at MNP

Source: Hemani (2013)

Social and cultural barriers consisting of lack of:

– Women empowerment
– People ownership
– Villager's willingness to learn, change bad fishing and agricultural practices
– Alternate to dependence on biomass for fuel wood needs

Such vulnerability assessment provides a base for identifying areas of concern and points of intervention by estimating the likelihood of future climate change and its impacts along with the socioeconomic and environment conditions in future. Current climate variability always becomes starting point of adaptation at the local level.

To address each area of concern, adaptation plan consisting of goals with various adaptation options for each goal with time frames, barriers in achieving these measures, co-benefits, and key stakeholders were created.

Thus, six adaptation goals which would increase livelihood security and human well-being were:

1. Creating public awareness about climate change, disaster prevention response: helps in capacity building
2. Provide safe and consistent drinking water and water for other (domestic, agriculture) needs: helps in adapting against decreased water availability
3. Provide diversified livelihoods and aid in livelihood sustenance: helps in improvement of livelihoods
4. Improvement of built environment: helps in strengthening and building infrastructure
5. Human safety and enhanced human safety: helps in adapting against health impediments
6. Functioning of healthy coastal ecosystem: helps cater to enhancing and conserving of coastal ecosystem

Since current vulnerability is majorly due to lack of development, it would be implementation of development plans which by default become the entry points for mainstreaming climate change adaptation. Next section brings an understanding of the mechanisms of governmental, institutional, and political efforts which can be contextualized and leveraged to define pro-poor adaptation outcomes while addressing developmental goals.

Lowering Vulnerability Through Linking of Development Initiatives to Climate Change Approach

In order to curb impacts of global climate change, effort needs to be made from global to local level as shown in Fig. 8. It also shows link between global, national, and state development goals with global, National, and State Action Plans for Climate Change (NAPCC and SAPCC).

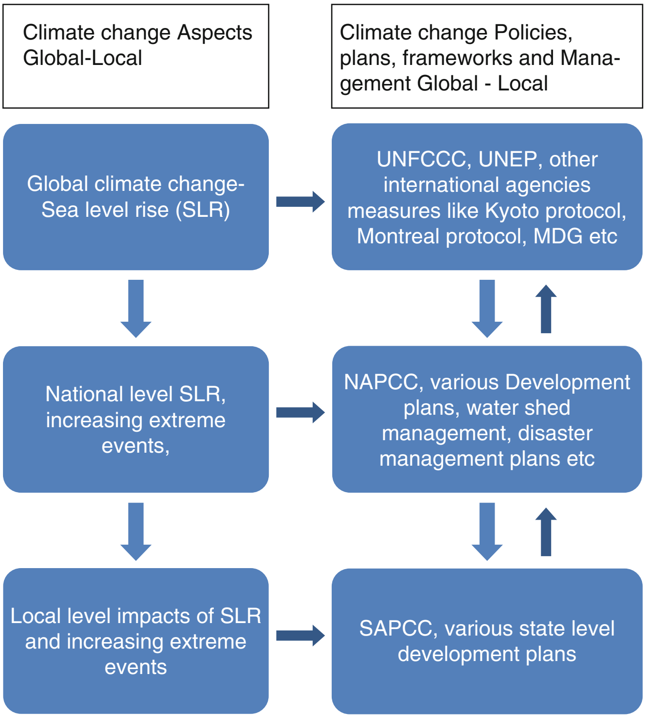

Fig. 8 Institutional arrangement for addressing climate change global to local

To address the research question with the purpose of mainstreaming climate change, six adaptation goals identified for the study area were linked to four MDG and various development goals at national and state level to address their current vulnerabilities (Table 5).

To execute this step, against each adaptation goal, relevant national and state development scheme were judged for its applicability to cater to current vulnerability, its relevance to adaptation efforts, and whether there is a need to enhance that scheme to cater to future climate vulnerability. Table 6 shows link between existing development plans to climate change adaptation.

Adaptation Strategy

Once the current concerns were identified, the remaining part of the strategy involved creating adaptation plan by leveraging development plans to cater to identified issues. The adaptation plan was based on identification and prioritizing of the adaptation options.

This stage involves contribution of the stakeholders, keeping in mind the needs of the most vulnerable groups. Implementation of the identified adaptation measure should be based on the prioritization of the adaptation options. Stakeholder review

Table 5 Linking MDG to development goals

Millennium development goals	Various development plans national level	Various development plans state level	Linked to which adaptation goals of this study
MDG 1: Eradicate extreme poverty and hunger	• Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) • National rural livelihood mission • Indira housing scheme	Sardar Patel housing scheme	Goal 3. Provide diversified livelihoods and aid in livelihood sustenance
MDG 2: Achieving universal education	• Universal Elementary Education (UEE) • Mid-day meal scheme		Goal 3: Provide diversified livelihoods and aid in livelihood sustenance
MDG 3: Promote gender equality and empower women	• Targeted provision for girls under UEE • Kasturba Gandhi Balika Vidyalaya (resident girl child school) scheme • Balika Samriddhi scheme (girl child development scheme)	Women self-help group (SHG) scheme	Goal 3: Provide diversified livelihoods and aid in livelihood sustenance
MDG 7: Ensuring environment sustainability	• National Rural Drinking Water Program (NRDWP) • Green India mission under NAPCC • Total Sanitation Campaign (TSC) • Nirmal Gram Puraskar to boost TSC (award for village leading TSC) • IWMP (integrated water management) program • ICZMP (Integrated Coastal Zone Management Program) • National Solar Mission under NAPCC • Social forestry • Prime minister village road scheme • SIPC (salinity ingress prevention cell) •MGNREGA	• Gokul gram scheme (village development scheme) • Nirmal Gujarat scheme (clean and healthy village scheme) • Panchavati scheme (Village Greening scheme) • Jamin Sampadani scheme (village development scheme) • Gram Mitra scheme (friends of village scheme)	• Goal 2: Provide safe and consistent drinking water and water for other (domestic, agriculture) needs • Goal 4: Improvement of built environment • Goal 5: Human safety and enhanced human safety • Goal 6: Functioning of healthy coastal ecosystem

Table 6 Linking national and state development goals to adaptation goals

Component: Goal	Policy/project	Policy brief	National/state driven	Target group	Relevance and applicability w.r.t climate change adaptation (CCA)	Rationale	Policy updation needed w.r.t CCA?
Creating public awareness about climate change, disaster prevention response	Friend of village scheme	It appoints individuals in the village who educate villagers on various development schemes. Each appointee would deal in the area of agriculture, education, health, development, and human welfare, respectively	State driven	Rural community	High	Awareness is the first step towards change	Yes, keeping in view future climate changes, appointed staff can be trained to train the villagers to increase the awareness and need of community and individual-level participation to increase their adaptive capacity

(*continued*)

Table 6 (continued)

Component: Goal	Policy/project	Policy brief	National/state driven	Target group	Relevance and applicability w.r.t climate change adaptation (CCA)	Rationale	Policy updation needed w.r.t CCA?
Water: provide safe and consistent drinking water and water for other (domestic, agriculture) needs	National rural drinking water program	Aims to provide every rural person with adequate safe water for drinking, cooking, and other domestic basic needs on a sustainable basis	Center driven, partial funding, state into partial funding and implementation	Rural community	High	To ensure the 40 l/capita/day water for rural population needs even in the face of climate variability and make provision for alternate source of potable water	Yes, to ensure the fulfillment of sustained water needs in face of climate change and variability
	Integrated watershed management program	Aims to restore ecological balance by harnessing, conserving, and developing degraded natural resources such as soil, vegetative cover, and water	Center driven and funded, state implementation	All community	High	Climate variability is affecting the drought-prone areas with reduced forest cover, reducing water table, and a shortage of drinking water, fuel, and fodder IWMP caters to these needs	Yes, to ensure soil and water conservation in case of future climate change

	MGNREGA	Aims at enhancing the livelihood security of people in rural areas by guaranteeing 100 days of wage employment in a financial year to a rural household whose adult members volunteer to do unskilled manual work	Center driven, partial funding, state: partial funding and implementation	Rural community	High	Along with livelihood security, it also provides environment protection, hence enhancing adaptive capacity and reducing vulnerability	Yes, already guidelines are there to converge MGNREGA and IWMP program and agriculture program
	Salinity ingress prevention and control scheme	Due to salinity ingress in the underground water, suggested construction of tidal regulators and weirs near the ocean bank, refilling lakes, refilling reservoirs, check dams, and spreading channel, etc., near the inside land area coastal Gujarat state	Center funded	Coastal communities	High	Efforts are such that it prevents salinity from spreading further	Yes, keeping in view the consequences of future climate change of (SLR and coastal inundation)

(*continued*)

Table 6 (continued)

Component: Goal	Policy/project	Policy brief	National/state driven	Target group	Relevance and applicability w.r.t climate change adaptation (CCA)	Rationale	Policy updation needed w.r.t CCA?
Livelihood: provide diversified livelihoods and aid in livelihood sustenance	Universal education for all	Free primary education for children	Center driven, state implementation	All children	Medium	Increasing the education level may bring other opportunities of employment rather than just natural resource-dependent employments	–
	MGNREGA	As mentioned previously					
	Women SHG scheme	To enable the poor women, particularly in rural areas of Gujarat to improve their access to resources and strengthen livelihoods and quality of life	State driven	Rural community	Medium	Women empowerment can lead to better decision making and alter source of income and hence increasing adaptive capacity of the household	–

	National rural livelihood mission	Aims to reduce poverty among rural BPL by promoting diversified and gainful self-employment and wage employment opportunities which would lead to an appreciable increase in income on sustainable basis	Center driven, state implementation	Rural – BPL	High	May bring other opportunities of employment rather than just natural resource-dependent employments	–
Infrastructure and institutional setup: improvement of built environment	MGNREGA	As mentioned previously					
	Jamin Sampadani scheme	In order to increase standard of rural life, structural facilities, viz., drinking water, sewerage, street lighting electricity in house internal roads, and approach roads, should be included under the scheme	State driven	Rural community	Medium	It provides basic amenities, hence increasing adaptive capacity	Yes, can enhance keeping in mind climate lens. Sewerage network must be developed keeping in mind the extreme rainfall and runoff

(*continued*)

Table 6 (continued)

Component: Goal	Policy/project	Policy brief	National/state driven	Target group	Relevance and applicability w.r.t climate change adaptation (CCA)	Rationale	Policy updation needed w.r.t CCA?
	Prime minister village roads scheme	To provide connectivity, by way of an all-weather road, to the eligible unconnected habitations in the rural areas with a population of 500 persons and above in plain areas	Center driven, partial funding, state into partial funding and implementation	Rural community	Medium	Internal village roads are temporary, while main road is still tar road and connected to highway	–
	Total sanitation campaign	It is a comprehensive program to ensure sanitation facilities in rural areas with broader goal to eradicate the practice of open defecation	Center driven, partial funding, state into partial funding and implementation	Rural community	Medium	Increasing frequency of floods in the future would increase water-borne diseases, reach to poor community toilets or at household remains	–

	Gokul Gram Scheme	For overall development and fulfilling basic amenities of the villages	State driven	Rural community	Medium	Helps building the infrastructure, reduces vulnerability	–
	Clean village, healthy village scheme	Financial assistance given for clean village	State driven	Rural community	Medium	Flooding of areas, unpicked and untreated solid waste increase diseases, affects health	–
	Indira Gandhi housing scheme/ (Sardar Patel Housing Scheme)*	Provides assistance to BPL who are either houseless or have inadequate housing facilities for constructing a safe and durable shelter for environmentally sound habitat with adequate provisions	Center policy making and partial funding, state into partial funding and implementation/ (state funded)*	Rural – BPL	High	Poor and marginalized households are more vulnerable as their houses are majorly built on temporary structures as they lack monetary support	Yes, keeping in mind the extreme events, location of the houses, and construction of the houses should be revised which will depend on the state- and village-specific development plans

(*continued*)

Table 6 (continued)

Component: Goal	Policy/project	Policy brief	National/state driven	Target group	Relevance and applicability w.r.t climate change adaptation (CCA)	Rationale	Policy updation needed w.r.t CCA?
	Panchavati scheme	Aims at the welfare of rural people to develop parks in the village with necessary facilities. Trees can be suggested by villagers and may also be grown in wasteland near the village	State driven	Rural community	High	Increase in green cover can lead to co-benefit of mitigation along with adaptation. Horticulture trees can reap monetary benefit to the community along with increase in water table	–
Natural resource dependence: functioning of healthy coastal ecosystem	Social forestry	Aims to take off pressure from existing forests by planting trees on all unused and fallow land, thus helping in social, rural development, and environment protection	Central Ministry driven	All population	High	-do-	–

	NAPCC: Solar mission	Promotes ecologically sustainable growth while addressing India's energy security challenge by introducing solar renewable energy	Central Ministry driven	All population	High	Leads to energy-efficient economic development having co-benefit of adaptation and mitigation	–
	Integrated Coastal Zone Management Program	Promotes (1) coastal resource conservation and management, (2) monitoring, (3) socioeconomic development, (4) geo-spatial mapping for scientific database	Central Ministry driven	Initiated for states of Gujarat, Orissa, and West Bengal later for all remaining 6 coastal states	High	Contribute towards increased understanding and acceptance of the need to protect, conserve, and regenerate coastal natural resources by local rural communities	Yes, revision of the hazard mapping and shoreline protection measures keeping in view the future extreme events

and prioritization of the options was not done in this case as this was a part of academic research work, but it is a must for live projects.

Identifying Adaptation Options

In this research emphasis was on identifying interventions from the existing development plans and policies. This step was author initiated, but in live projects, it involves finding feasibility of implementation of the measure, evaluation of estimated benefit, and cost from the measure along with stakeholder consultation involving government officials, local community groups, and experts from the field. This would also create awareness about the views of different stakeholders, promote dialogue, and create collective interpretation and ownership of suggested modifications. It needs to be documented.

Table 7 consists of list of adaptation options. Under each adaptation goals, various adaptation measures are listed.

Prioritizing and Selecting Adaptation Options

For prioritizing adaptation options, various tools like cost-benefit analysis, cost-effectiveness analysis, expert judgment, multi-criteria analysis can be used. When quantification and valuation of adaptation options is not possible in monetary terms such as the benefits of preserving biodiversity, MCA is used for prioritizing options (OECD 2009).

This research uses MCA for prioritizing options. Here weightage is given to each of the parameter from 0 to 1 depending on flexibility, potential cost, and ease of execution. An overall score of each action is obtained through summation of the weightage to each parameter, and the options with the highest scores are prioritized accordingly where there are multiple competing criteria (UNFCCC 2011).

Some of the parameters used in this study helped determine the assessment of adaptation options for prioritizing them including:

- Economy-wide impacts: Many impacts are influenced by global market events in response to climate change.
- Hard as opposed to soft adaptation options: Hard including technical/engineering options and soft options including those dealing with behavior change, policies, and instruments.
- Ancillary benefits: Along with the reduction of damages caused by current climate variability, they also bring in other ancillary benefits like job creation, net benefits to the economy through energy or water efficiency, etc.
- Public as opposed to private adaptation: It is important to recognize that individuals will respond to future climate variability, and their response will depend on the public actions that are taken.
- Adaptation-mitigation linkages: Adaptation actions that have consequences for mitigation. For example, improving green cover can bring in reduced CO_2, reducing heat stress, improving health, as well as improving ground water table.

Refer Table 7 for the MCA.

Table 7 Adaptation options and MCA

Major component	Adaptation options for noted issues	Hard (0.25)/ soft option (1)	Economy wide impact (changes with global (0.25)/ national (0.5) and local economy/ none (1)	Public (hard −0.25, soft – 0.5)/private (0.5)/Public Private Partnership (1)	Adaptation – mitigation linkages 1/0 if none)	Ancillary benefits (1/0 if none)	Total score (out of 5	Ranking options
Sociodemographic	Training and raising public awareness on what is climate change and for active adaptation to disasters and climate change impacts	1	1	1	1	1	5	1
	Making a climate change committee and maintaining a climate change register and impacts on various sectors like health, agriculture, biodiversity, etc., for each village	1	1	1	1	1	5	1
Water	Training on climate change and water variability and the need to conserve water especially to farmers	1	1	1	1	1	5	1
	Training for optimum use of water, water conservation techniques demonstration, and improving agricultural practices under Gram Mitra scheme	1	1	1	1	1	5	1

(*continued*)

Table 7 (continued)

Major component	Adaptation options for noted issues	Hard (0.25)/ soft option (1)	Economy wide impact (changes with global (0.25)/ national (0.5) and local economy/ none (1)	Public (hard −0.25, soft – 0.5)/private (0.5)/Public Private Partnership (1)	Adaptation – mitigation linkages 1/0 if none)	Ancillary benefits (1/0 if none)	Total score (out of 5	Ranking options
	Provision of tap water in 90:10 partnership with villages	1	1	0.5	0	1	3.5	5
	Existing ongoing SIPC works	0.25	1	0.25	1	1	3.5	5
	Building of community rain water harvesting tanks to store rain water	0.25	1	1	1	1	4.25	3
	Building of conservation ponds and recharge wells under MGNREGA scheme	0.25	1	1	1	1	4.25	3
Livelihoods	Creation of microfinance banking facilities	0.25	0.5	0.5	0	1	2.25	9
	Awareness camps for benefits of education/ teaching under CSR (corporate social responsibility)	1	1	1	1	1	5	1

	Training for use of optimum fertilizers, switching to organic farming, and growing indigenous grains	1	1	1	1	1	5	1
	Shifting to drought resistant variety of grains	0.25	0.5	0.5	1	1	3.25	6
	Training and awareness among villagers on usage of proper net and about fish catch season	1	1	1	1	1	5	1
Infrastructure	Build pucca roads under MGNREGA, Jamin Sampadani scheme, prime minister village road scheme	0.25	1	1	0	1	3.25	6
	Provision of bins for waste segregation	1	1	0.5	0	1	3.5	5
	Clean village competition among villages	1	1	0.5	0	1	3.5	5
	Provision of storm water drain network*	0.25	0.5	0.25	1	1	3	7
	Channelizing storm water to ponds for recharging*	0.25	0.5	0.25	1	1	3	7
	Building Sanitation	0.25	1	1	0	1	3.25	6
Health and communication	Health camps	1	1	1	0	1	4	4
	Private visiting doctors	1	1	1	0	1	4	4
	Infrastructure setup for PHC (can turn out to be long term)	0.25	1	1	0	1	3.25	6

(*continued*)

Table 7 (continued)

Major component	Adaptation options for noted issues	Hard (0.25)/ soft option (1)	Economy wide impact (changes with global (0.25)/ national (0.5) and local economy/ none (1)	Public (hard −0.25, soft – 0.5)/private (0.5)/Public Private Partnership (1)	Adaptation – mitigation linkages 1/0 if none)	Ancillary benefits (1/0 if none)	Total score (out of 5	Ranking options
	Training and awareness among villagers on interpretation and usage of weather warning systems	1	1	1	1	1	5	1
	Phase-wise implementation of weather warning systems	0.25	1	0.25	0	1	2.5	8
	Revision of emergency plan with flood maps, emergency meet points, evacuation plans and maps	1	1	0.5	0	1	3.5	5
Biophysical	Over wasteland: under Panchavati scheme, develop gardens	1	1	0.5	1	1	4.5	2
	Community forest under social forestry	1	1	0.5	1	1	4.5	2

	Tree plantation as a part of CSR drive by industries	1	1	1	1	1	5	1
	Harnessing solar energy for cooking purposes	1	1	0.5	1	1	4.5	2
	Agriculture base villages have potential to use biogas plant for cooking needs	1	1	0.5	1	1	4.5	2
	Training and awareness among villagers of importance of biodiversity	1	1	1	1	1	5	1
	Vigilance and recording of species loss if any	1	1	0.5	1	1	4.5	2
	Plantation activity by the green committee already in the village formed under ICZMP	1	1	1	1	1	5	1
	Payment in terms of environment taxes for ecosystem services by the industries	1	1	1	1	1	5	1

*Info. from data collected by Village head in 2011

Adaptation Plan

Finally an adaptation plan was created for the study region as enlisted in Table 8. For each adaptation measure suggested enlists a time frame by when they should be implemented, who would be the stakeholders, what are the constraints, which existing developmental plan or policy that targets similar concern, and what are the co-benefit if it exists (whether the adaptation measure can be also linked to mitigation action) and the category of the measure (whether the adaptation measure category is of no regret, low regret, or climate justified).

Literature review suggests “no regret” adaptation measures as those which provide net benefits regardless of climate change. “Low regrets” measures as the ones where moderate levels of investment increase capacity to cope with future climate risks (UNDP-UNEP 2011) while “climate justified” measures as the ones which depend on projections of changes in climate to justify their benefits (OECD 2009). It is important to know the level of regret as it suggests different implications with respect to climate information, timing of investment, planning horizon, and economic evaluation (UNDP-UNEP 2011) and also suggests which measure can be taken up easily and first.

Adaptation measures suggested here either deal with asset upkeep, protection needed during a natural disaster like bio shields, etc., and asset building like salinity ingress prevention canals needed to withstand projected long-term gradual climate changes along with some measures like training leading to awareness and behavioral changes and investment into early warning system which are important for enhancing livelihood resilience. Financial resources like credit or insurance are vital for recovery and long-term adaptation (CARE International, July 2010).

Some Practical Challenges

Such studies are always bound with some practical challenges which would need local intervention, some of which would be common for developing countries in general are enlisted here.

While social vulnerability assessment is indicator based, complex social interactions may be difficult to be factored in the form of indicators and hence may get left out in the overall vulnerability assessment.

Political and social will for adoption of development initiatives which also enhance climate change adaptation is a challenge. Appropriate intervention by stakeholders is needed.

Moreover, climate change and variability will bring various issues which have cross-sectoral impacts; hence, a need for alliance between various sectoral departments while comprehensively designing the adaptation options with multi-stakeholders needs to be taken up which is generally found lacking.

Also future adaptation measures are sought by projecting future vulnerability that is based on future scenarios of climate change, socioeconomic, and environment conditions. It can only be validated once the future climate event occurs and the other socioeconomic and environment conditions then.

Table 8 Adaptation plan

Major component	Issues	Short-term measure (1 to 5 years) action plan (2013–2017)	Time frame	Stakeholder	Medium-term measure (5 to 10 years) long term (10 to 20 years)	Stakeholder	Existing policy/ program which is/can be used	Constraints	Additional/ co-benefits	Adaption measure category (no regret/ low regret/ climate justified)
Adaptation goal (1) creating public awareness about climate change, disaster prevention response										
Sociodemographic	Lack of awareness on climate change and its impacts	1. Training and raising public awareness on what is climate change and for active adaptation to climate change impacts	2013 onwards on continuous basis	NGO, state climate change department, Gram Panchayat[a]	1. Upkeep of training sharing scientific information wrt sectors, status of issues	NGO, state climate change department, Gram Panchayat	Can be targeted under SAPCC	1. Lack of fund	1. Public support during the execution of other actions mentioned below and hence ease of execution	No regret
		2. Making a climate change committee and maintaining a climate change register and impacts on various sectors like health, agriculture, biodiversity, etc., for each village	2013		2. Discussion and revision of action plan[a]			2. Lack of willingness and acceptance to learn from villagers side	2. People ownership created for works done	
								3. Lack of quality staff and material to train in vernacular language		

(*continued*)

Table 8 (continued)

Major component	Issues	Short-term measure (1 to 5 years) action plan (2013–2017)	Time frame	Stakeholder	Medium-term measure (5 to 10 years) long term (10 to 20 years)	Stakeholder	Existing policy/ program which is/can be used	Constraints	Additional/ co-benefits	Adaption measure category (no regret/ low regret/ climate justified)
Adaptation goal (2) provide safe and consistent drinking water and water for other (domestic, agriculture) needs										
Water	Water quality and availability	1. Training on climate change and water variability, the need to conserve water especially for farmers	2013 onwards	NGO, state climate change department, Gram Panchayat	Upkeep of training sharing scientific information w.r.t sectors, status of issues	Gram Panchayat, villagers	Can be targeted under SAPCC	1. Funding 2. Willingness to take ownership among villagers		No regret
		1. Training for water conservation techniques demonstration and improving agricultural practices under Gram Mitra scheme	2013 onwards on continuous basis	State govt. Gram Panchayat, NGO local people	1. Maintenance and upkeep of ponds, regular desilting, repairing, etc. 2. Water pricing schemes 3. Compulsory use of drip irrigation in case of irrigated land			Willingness by farmers to change practices		No regret
		Provision of tap water in 90:10 partnership with villages	2013–2017	WASMO (Water and Sanitation Monitoring Organization), NGO, villagers, private	Upkeep and maintenance of piped water	Gram Panchayat, villagers operations and maintenance committee	NRDWP			No regret

				company owning land (in case of Khijadiya salt pan workers colony)						
		Existing ongoing SIP works	Ongoing –2017	Narmada water resources, water supply, and Kalpsar department	Incorporating climate resiliency features in the SIPC future and pending activities	High-level committee for salinity ingress study	SIPC	Cost, other logistical arrangement for SIP works	Benefit to farmers for irrigation	Climate justified
		1. Building of community rain water harvesting tanks to store rain water	2013–2015	NGO, state climate change department, Gram Panchayat	Upkeep of ponds and recharge wells	Gram Panchayat, villagers operations and maintenance (O&M) committee	MGNREGA	1. Funding	Increases the water recharge and availability of water sources	No regret
		2. Building of conservation ponds and recharge wells under MGNREGA scheme						2. willingness to take ownership among villagers		
								3. Gram Panchayat's willingness to take activities under MGNREGA		

(*continued*)

Table 8 (continued)

Major component	Issues	Short-term measure (1 to 5 years) action plan (2013–2017)	Time frame	Stakeholder	Medium-term measure (5 to 10 years) long term (10 to 20 years)	Stakeholder	Existing policy/ program which is/can be used	Constraints	Additional/ co-benefits	Adaption measure category (no regret/ low regret/ climate justified)
Adaptation goal (3) provide diversified livelihoods and aid in livelihood sustenance										
Livelihoods	Lack of credit societies (high level of interest rate to middle men esp. for Rasulnagar village)	Creation of microfinance banking facilities	2013–2015	Banks				Willingness by banks to set up small units		Low regret
	Lack of education level and lack of livelihood	1. Awareness camps for benefits of education	2013 onwards	State government, NGO	Introduction of vocational classes	NGO	UEE	1. Willingness to learn among villagers	Improved adaptive capacity with increased livelihood options on being educated	No regret
		2. Teaching under CSR activity	2014 onwards					2. Willingness among companies to come and teach		
	Lack of good agricultural practices	1.Training for use of optimum fertilizers, switching to organic farming, and growing	Various camps throughout 2013–2017	State government, National Bank for Agriculture and Rural Development (NABARD), agriculture	Removing subsidies on water, electricity, and fertilizers	State government		Willingness by farmers to change practices		No regret/ low regret

		indigenous grains		department NGO						
		2. Shifting to drought resistant variety of grains								
	Lack of good fishing practices	Training and awareness among villagers on the usage of proper net and not to catch fish in the spawning season		Fishers department, NGO				Willingness by fishermen to change practices		No regret
Adaptation goal (4) improvement of built environment										
Infrastructure and institutional setup	Poor infrastructure and lack of conveyance to connecting highway or major city	Build metaled roads	2013–2015	Gram Panchayat, villagers	Upkeep and maintenance of roads under MGNREGA	Gram Panchayat, villagers	MGNREGA, Jamin Sampadani scheme, Prime minister village road scheme	Lack of resources (time, money, manpower) and rural look out may be low on priority	Reduced health hazards	Low regret
	Lack of solid waste collection management	1. Provision of bins for waste segregation	2013–2014	State govt. for fund, Gram Panchayat, NGO, local people			Nirmal Gujarat scheme, Swatchcha Gram scheme	Funding, willingness to take ownership among villagers	Reduced health issues	No regret
		2. Clean village competition among rural villages	2014 onwards							
	Lack of drainage and no sewerage	1. Provision of storm water drain network*	2013–2017	GWSSB (Ground Water Supply and Sewerage Board), Gram Panchayat local villagers	1. Provision of sewerage network	GWSSB, Gram Panchayat local villagers O&M committee		Funding lack on priority for rural lookout		Low regret*/ climate justified
		2. Channelizing storm water to			2. Treating the sewerage waste before					

(*continued*)

Table 8 (continued)

Major component	Issues	Short-term measure (1 to 5 years) action plan (2013–2017)	Time frame	Stakeholder	Medium-term measure (5 to 10 years) long term (10 to 20 years)	Stakeholder	Existing policy/ program which is/can be used	Constraints	Additional/ co-benefits	Adaption measure category (no regret/ low regret/ climate justified)
		ponds for recharging*			releasing to river or sea					
					3. Upkeep of the storm water drains					
	Lack of sanitation facilities	Building sanitation facilities	Ongoing –2017	Gram Panchayat, NGO, CSR funding, MNP			TSC, Nirmal Gujarat scheme			Low regret
Adaptation goal (5) human safety and enhanced human safety										
Health and communication	Lack of PHC	1. Health camps	2013 onwards	State government				Funding, lack on priority for rural lookout		Low regret
		2. Private visiting doctors								
		3. Infrastructure setup for PHC (can turn out to be long term)	2013–2017							
	Lack of weather warning system	Training and awareness among villagers on interpretation and usage of weather	2017	Indian Meteorology Department (IMD), NGO	Upgrade the warning system, upkeep of system	IMD, local contract		Funding lack on priority for rural lookout	Due to increased preparedness reduced loss to life and monetary loss	Climate justified

		warning systems								
		Phase-wise implementation of weather warning systems								
	Lack of emergency planning	Revision of emergency plan with flood maps, emergency meet points, evacuation plans and maps	2013–2017	Gujarat State Disaster Management Agency (GSDMA)	Evacuation maps and plans alternate route to connect this village with highway as of now there is only one way to reach the village	Climate change department, GSDMA		Lack of resources (time, money, manpower) and rural look out may be low on priority		Climate justified
Adaptation goal (6) functioning of healthy coastal ecosystem										
Natural resources dependence	Lack of green cover	Over wasteland	2013–2016	1. Gram Panchayat, state dept.	Maintenance and upkeep of planted trees	Gram Panchayat	Panchavati scheme social forestry, MNREGA	Upkeep of parks (managing CPR)	Reduce storm water runoff, increase in water table, increase in cohesion among community, improve quality of life	No regret
		1. Under Panchavati scheme, develop gardens		2. Gram Panchayat and Forest department						
		2. Community forest under social forestry (local species of trees to be chosen, horticulture trees for social forestry can provide		3. Private companies falling under companies bill for CSR mandate						

(*continued*)

Table 8 (continued)

Major component	Issues	Short-term measure (1 to 5 years) action plan (2013–2017)	Time frame	Stakeholder	Medium-term measure (5 to 10 years) long term (10 to 20 years)	Stakeholder	Existing policy/ program which is/can be used	Constraints	Additional/ co-benefits	Adaption measure category (no regret/ low regret/ climate justified)
		monetary benefits also)								
		3. Tree plantation as a part of CSR drive by industries								
	Dependence on biomass for fuel need	1. Harnessing solar energy for cooking purposes	2013–2017	Gujarat Energy Development Agency (GEDA), Gram Panchayat, local villagers	Harnessing wind and tidal energy to generate electricity, earn carbon credits, income from it can be used to enhance facilities of the village		National Solar Mission under NAPCC	Funding, acceptance of new technology	Increased alternate source of income for the village, reduced GHG emissions	Low regret
		2. Villages with agriculture (*except Rasulnagar/ fishermen villages) has potential to use biogas plant for cooking needs (carbon credits earned can be used to enhance the facilities of the villages)								

Biophysical	Loss of biodiversity – mangroves, corals, sea grass, dugong, etc.	1. Training and awareness among villagers of importance of biodiversity	2013 onwards	GEC MNP, polluting industries along the coast, local green committee	Upkeep and maintenance of biodiversity, strong vigilance of polluting industries	Villagers committee, GPCB (Gujarat Pollution Control Board)	ICZMP	Vigilance on polluting industries, noncorrupt officials		No regret
		2. Vigilance and recording of species loss if any								
		3. Plantation activity by the green committee already in the village formed under ICZMP								
		4. Payment in terms of environment taxes for ecosystem services by the industries	2014 onwards							
Village specific – Rasulnagar										
Livelihood	No fish landing center	Providing fishing landing center	2013–2016	Gram Panchayat, villagers, fisheries department	Upkeep and maintenance of the fish landing center	Gram Panchayat, villagers		Funding, low priority		Low regret

(*continued*)

Table 8 (continued)

Major component	Issues	Short-term measure (1 to 5 years) action plan (2013–2017)	Time frame	Stakeholder	Medium-term measure (5 to 10 years) long term (10 to 20 years)	Stakeholder	Existing policy/ program which is/can be used	Constraints	Additional/ co-benefits	Adaption measure category (no regret/ low regret/ climate justified)
Sociodemographic	Lack of women empowerment and involvement in alternate livelihoods	Awareness camps for women empowerment, women SHG formation skills training program	2013–2014	NGO, Gram Panchayat				Willingness to accept idea of women empowerment	Alternate sources of livelihood	No regret
Natural disaster and climate variability	Impact due to storm surges	Creating sand bunds, creating living shorelines*	2013–2015	Gram Panchayat, villagers, GSDMA	Creating surge protection walls	GSDMA				No regret* climate justified
Village specific – Khijadiya										
Biophysical	Impact on coastal wetland	1. Involvement of villagers in the upkeep of the wetlands 2. Coastal wetland protection and restoration	2013–2017	MNP, villagers	Maintenance of wetland and maintenance of the level of freshwater suitable for the migratory birds	MNP, local villagers	ICZMP, MGNREGA	Lack of villagers knowledge leading to malpractices	Alternate source of livelihood	No regret
	Development of common pastoral land	Involvement of villagers in the developing of pastoral land for cattle fodder	2013–2017	Gram Panchayat, villagers	Maintenance of pastoral land	Gram Panchayat, villagers		Willingness to take ownership among villagers		

Infrastructure	Poor housing infrastructure for salt pan workers which also a low-lying area flooded every year	Salt pan workers company to provide cyclone, flood-resistant housing	2013–2017	Salt pan company			Indira housing scheme, Sardar Patel housing scheme,	Company unwilling to spend extra money on the required changes		Climate justified
Village specific – Khara Beraja										
Infrastructure	Poor housing infrastructure	To provide cyclone, flood resistant housing	2013–2017	Gram Panchayat, state department, villagers			Indira housing scheme, Sardar Patel housing scheme,	Funding, low priority		Climate justified

*Gram Panchayat: local self-government at village level

Conclusion

This research is a preliminary attempt to address the current vulnerability issues through integration of development and adaptation measures for coastal rural communities. The main objective of this study was to leverage national and state development goals in creating adaptation plan catering to current vulnerability for the study region.

With respect to Indian coastal village's vulnerability study, developmental issues like lack of infrastructure, literacy levels, etc., along with malpractices in agriculture and fishing, several social setup issues, and effect of pollution due to the presence of chemical industries in the vicinity can be considered as the major causes for increasing vulnerability. Developing specific indicators and a comprehensive field survey along with involvement of stakeholders from the beginning will help to find the current baseline and underlying issues which could be addressed in the adaptation measures.

This case study illustrates many and varied opportunities of intervention and highlights how development and adaptation can be interlinked. However, these interlinkages are yet to be recognized by the government. For example, existing development plans like the ongoing ICZMP project can be leveraged by integrating climate lens into it in order to reduce the current and future vulnerability.

Adaptation plan along with short-term and long-term measures with realistic time frame was made where stakeholder consultation was not done, but it can be taken up as way forward to make the suggested plan functional.

Although local stakeholders and civic institutions have a role to play in addressing the current climatic challenges, it is the government institution to take lead with strong policy, political will, and good governance mechanism. Moreover, cross sectoral linkages to address climate change impacts could be handled by existing climate change department of the state. It can act as a steering body to alias with all the necessary departments and leverage their work to incorporate climate variability and change.

Further such studies can be supported by policy researches so that national- and local-level policies and programs can be leveraged keeping in view the global perspectives, researches, and advancements in the field of climate science.

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Arable Crop Farmers' Decision Making and Adaptation Strategies on Climate Change in Ogun State, Nigeria

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Contents

Abstract

Climate and rural farmers' resource allocation behavior are primary determinants of agricultural productivity in Nigeria. Hence, knowledge of the rural farmers about climate change is important in order to offer adaptation practices

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that mitigate its adverse effects. This study thus investigated the effects of climate change at the grassroots by considering the determinants of the communities' adaptation to changes in climate in Ogun State, Nigeria. The study utilized primary data collected from 150 arable crop farmers selected across Ogun State through a multistage sampling technique. The data were obtained through administration of questionnaire designed to elicit information on socioeconomic characteristics and adaptation behaviors of the respondents to climate change. The multinomial logit regression model was used to capture choice probabilities across the various options of climate change adaptation strategies. Most (81.08 %) of the arable crop farmers were males with an average farming experience of 24 years. Some (22.97 %) respondents did not take up any climate change adaptation strategy, 45.95 % targeted rains to plant, 12.16 % used multiple strategies, 10.81 % adopted good soil conservation techniques, while 8.11 % adopted wetland farming. The significant factors explaining the choice of climate change adaptation strategies taken up by the respondents were household size ($p < 0.05$), gender ($p < 0.10$), years of residence in a community ($p < 0.05$), educational level ($p < 0.10$), frequency of extension contact ($p < 0.01$), access to agricultural credit, and income from secondary occupation ($p < 0.05$). This paper provides interesting information on natural adaptation practices and these indigenous approaches would be useful to researchers and policy makers worldwide.

Keywords
Arable crop farmers • Decision making • Adaptation strategies • Climate change

Introduction

Agriculture places heavy burden on the environment in the process of providing humanity with food and fiber, while climate is the primary determinant of agricultural productivity. Studies indicate that Africa's agriculture is negatively affected by climate change (Pearce et al. 1996; McCarthy et al. 2001). Given the fundamental role of agriculture in human welfare, concern has been expressed by federal and state agencies and other countries regarding the potential effects of climate change on agricultural productivity. Climate change according to IPCC (2001b) can be defined as the change in the state of the climate that can be identified using statistical data by changes in the mean and variability of climate properties that has persisted for an extended period, typically decades or longer. It also refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage however differs from that in the United Nations Framework Convention on Climate Change (UNFCC, 1992), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of global atmosphere and that is, in addition to natural climate variability, observed over comparable time period (Currents 2008).

Interest in this issue has motivated a substantial body of research on climate change and agriculture over the past decade (Fischer et al. 2002; Wolfe et al. 2005; Lobell et al. 2008). Climate change is expected to influence crop and livestock production, hydrologic balances, input supplies, and other components of agricultural systems. However, the nature of these biophysical effects and the human responses to them are complex and uncertain.

Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (Intergovernmental Panel on Climate Change 2001a). Common adaptation methods in agriculture include use of new crop varieties and livestock species that are more suited to drier conditions, irrigation, crop diversification, mixed crop livestock farming systems, and changing planting dates (Bradshaw et al. 2004; Kurukulasuriya and Mendelsohn 2006; Nhemachena and Hassan 2007).

It is evident that climate change will have a strong impact on Nigeria – particularly in the areas of agriculture, land use, energy, biodiversity, health, and water resources. Nigeria, like all the countries of sub-Saharan Africa, is highly vulnerable to the impacts of climate change (IPCC 2007; Nigeria Environmental Study Team 2004). Rain-fed agricultural practice and fishing activities from which two-third of the Nigerian population depend primarily on foods and livelihoods are also under serious threat besides the high population pressures of 140 million people surviving on the physical environment through various activities within an area of 923,000 km^2 (IPCC 2007; NEST 2004).

Food crop farmers in Southwestern Nigeria provide the bulk of arable crops that are consumed locally and transported to other regions in the country. These farmers are also experiencing climate change even though they have not considered its deeper implications. This is evidenced in the late arrival of rain, the drying-up of stream and small rivers that usually flow year-round, the seasonal fluctuation of rains, and the gradual disappearance of flood-recession cropping in riverine areas (Building Nigeria's Response to Climate Change 2008).

Consequently, this research intends to investigate the effects of climate change at the grassroots by considering the determinants of the communities' adaptation to changes in climate. This is important because sustainability of agricultural production depends largely on actions of farmers and their ability to make decisions given the level of knowledge and information available to them. This study takes into account the local communities' understanding of climate change and assumed that these communities have an inborn, adaptive knowledge from which to draw and survive in high-stress ecological and socioeconomic conditions. The study further described the adaptation strategies of arable crop farmers to climate change and also estimated the determinants of arable crop farmers' decision on climate change adaptation strategies.

Methodology

Description of the Study Area

This study was carried out in Ogun State. Ogun State is one of the 36 states of the Federal Republic of Nigeria. It was carved out of the defunct Western State on the 3rd day of February, 1976, and it has a total land area of 16,409.26 km^2. The estimated population is 3,728,098 according to Nigerian 2006 National Census figure (Federal Republic of Nigeria (FRN) 2009). The climate of Ogun State follows a tropical pattern with the raining season starting about March and ending in November, followed by dry season. The mean annual rainfall varies from 128 mm in the southern parts of the state to 105 mm in the northern areas. The average monthly temperature ranges from 23 °C in July to 32 °C in February. The northern part of the State is mainly of derived Savannah vegetation, while the Central part falls in the rain forest belt. The southern part of the State has mangrove swamp. The geographical landscape of the state comprises extensive fertile soil suitable for agriculture and savannah land in the northwestern part of the state, suitable for cattle rearing. There are also vast forest reserves, rivers, lagoons, rocks, mineral deposits, and an oceanfront. The rivers in the state provide veritable opportunities for farmers' to access the potentials of dry season as well as *fadama* farming.

The main occupation of the people of the state is farming, which is largely subsistence in scale.

The state is known to have a virile Agricultural Extension Programme which comprises four agricultural zones identified by OGADEP as Abeokuta, Ilaro, Ijebu, and Ikenne. Each zone is divided into blocks, and each block into circles or cells and each of these is anchored by a Village Extension Agent (VEA) who oversees the activities of farmers in his coverage area, while a Block Extension Agent (BEA) anchors a block by overseeing activities of farmers in the coverage area.

Data Types, Sources, and Sampling Technique

This study was based on primary data. The primary data were obtained through administration of structured questionnaire on arable crop farmers in the study area. Data collected included the arable crop farmers' socioeconomic and production characteristics, actual adaptation strategies adopted by the respondents, as well as barriers to adaptation faced in the study area. The sample size used for this study was 150 arable crop farmers. Multistage sampling technique was used to select arable crop farmers from whom data were generated for this study. The first stage of sampling involved a random selection of two zones from the four Ogun State Agricultural Extension Development Programme (OGADEP) zones, that is, Abeokuta and Ikenne zones (OGADEP divided the state into four zones – Abeokuta, Ilaro, Ijebu, and Ikenne, on the basis of geographical spread and ease of administration. Each zone is divided into blocks and each block into circles or cells and each of these is anchored by a Village Extension Agent (VEA) who oversees the activities of farmers in his

Table 1 Sampling procedure for the study

Stage	Procedure	Sampling frame
1.	Random selection of two zones from the four OGADEP zones	List of all the four OGADEP agricultural zones
2.	Proportion random selection of half of the total number of blocks within each selected zone	List of all blocks under the OGADEP agricultural zones selected
3.	Simple random selection of three cells each from the above selected blocks	List of all cells under the five OGADEP agricultural blocks selected
4.	Simple random selection of 10 respondents from each of the cells selected above	List of all arable crop farmers under each cell obtainable from OGADEP was the sampling frame

coverage area, while a Block Extension Agent (BEA) anchors a block by overseeing activities of farmers in the coverage area). The second stage involved a random selection of 50 % of the total number of blocks in both Abeokuta and Ikenne zones, resulting in the selection of three blocks from Abeokuta zone, and two blocks from Ikenne zone using list of blocks in the zones as the sampling frame. The third stage involved a random selection of three cells from each of the selected five blocks in each zone using the list of cells obtainable from OGADEP as the sampling frame. The fourth stage involved a random selection of 10 arable crop farmers from each of the selected cells (using a list of arable crop farmers from each cell obtainable from OGADEP) thereby giving a total number of 150 respondents.

The sampling procedure for this study is summarized in Table 1.

Analytical Techniques

Descriptive statistics and multinomial logit (MNL) regression model were used to analyze the data collected. The advantage of using MNL is that it permits the analysis of decisions across more than two categories, allowing the determination of choice probabilities for different categories of climate change adaptation being modeled by the study. It is also known for its computational simplicity in calculating the choice probabilities that are expressible in analytical form (Tse 1987). Hence, this model provides a convenient closed form for underlying choice probabilities with no need of multivariate integration, making it simple to compute choice situations characterized by many alternatives. The main limitation of the model is the independence of irrelevant alternatives (IIA) property, which states that the ratio of the probabilities of choosing any two alternatives is independent of the attributes of any other alternative in the choice set (Hausman and McFadden 1984; Tse 1987).

The decision of whether or not to use any adaptation option could fall under the general framework of utility and profit maximization. Consider a rational farmer who seeks to maximize the present value of expected benefits of production over a specified time horizon and must choose among a set of J adaptation options.

The farmer i decide to use j adaptation option if the perceived benefit from option j is greater than the utility from other options (say, k) depicted as

$$U_{ij}\left(\beta'_j X_i + \varepsilon_j\right) > U_{ik}\left(\beta'_k X_k + \varepsilon_k\right) \tag{1}$$

where j is not equal to k;

U_{ij} and U_{ik} are the perceived utility by farmer i of adaptation options j and k, respectively; and ε_j and ε_k are the error terms.

Under the revealed preference assumption that the farmer practices an adaptation option that generates net benefits and does not practice an adaptation option otherwise, we can relate the observable discrete choice of practice to the unobservable (latent) continuous net benefit variable as

$$\mathrm{Y}_{ij} = 1 \text{ if } U_{ij} > 0, \text{ and } \mathrm{Y}_{ij} = 0 \text{ if } U_{ij} < 0$$

In this formulation, Y is a dichotomous dependent variable taking the value of 1 when the farmer chooses an adaptation option in question and 0 otherwise. The probability that farmer i will choose adaptation option j among the set of adaptation options could be defined as follows:

$$P(Y = 1/X) = P\left(U_{ij} > U_{ik}\right)/X \tag{2}$$

$$\begin{aligned} &= P\left[\left(\beta'_j X_i + \varepsilon_i - \beta' k\, X_i - \varepsilon_k\right) > 0/X\right] \\ &= \mathrm{P}\left[\left(\beta'_\mathrm{j} - \beta'_\mathrm{k}\right) \mathrm{X}_i + \varepsilon_\mathrm{j} - \varepsilon_\mathrm{k}\right) > 0/\mathrm{X}\right] \\ &= \mathrm{P}\left(\beta^* \mathrm{X}_i + \varepsilon^* > 0/\mathrm{X}\right) = \mathrm{F}\left(\beta^* \mathrm{X}_i\right) \end{aligned} \tag{3}$$

In this analysis, the five climate change adaptation categories considered are given below:

1. Good soil conservation techniques.
2. Irrigation/drainage/wetland farming.
3. Targeting rains to plant.
4. Multiple strategies.
5. No adaptation: this was used as the reference category. In order to estimate this model, there was the need to normalize one category of the adaptation strategies, for effective analysis. This is also known as “reference state.”

where ε^* is a random disturbance term,

β^* is a vector of unknown parameters that can be interpreted as the net influence of the vector of explanatory variables influencing adaptation,

X_{is} are the explanatory variables, and they included the following:

X_1 = Farming experience in years

X_2 = Educational level

X_3 = Age in years

X_4 = Household size

X_5 = Years of residence in a community
X_6 = Secondary occupation income in naira
X_7 = Frequency of extension contact
X_8 = Gender
X_9 = Marital status
X_{10} = Religion (Islam = 1, Christianity = 2, traditional worshipper = 3)
X_{11} = Land size (ha)
X_{12} = Access to credit (access to credit = 1, and 0 if otherwise)
and F (β^* X_i) is the cumulative distribution of ε^* evaluated at β^* X_i.
The multinomial logit model is thus specified according to Green (2003) as

$$P_{ij} = \text{prob}(Y = 1) = \frac{e^{x'\beta}}{1 + \sum_{J=1}^{j} e^{x'\beta}} \tag{4}$$

where j = 1 ... n and

β is a vector of parameters that satisfy ln (P_{ij}/P_{ik}) = X' ($\beta_j - \beta_k$) (Greene 2003).

Unbiased and consistent parameter estimates of the MNL model in Eq. 4 require the assumption of independence of irrelevant alternatives (IIA) to hold. Specifically, the IIA assumption requires that the likelihood of a household using a certain adaptation measure needs to be independent of other alternative adaptive measures used by the same household. Thus, the IIA assumption involves the independence and homoscedastic disturbance terms of the adaptation model in Eq. 3. The validity of the IIA assumption is based on the fact that if a choice set is irrelevant, eliminating a choice or choice sets from the model altogether will not change parameter estimates systematically. Differentiating Eq. 3 with respect to each explanatory variable provides marginal effects of the explanatory variables given as

$$\partial p_j / \partial x_k = Pj \left[\beta_{kj} - \sum_{J=1}^{j-1} P_j \beta_{jk} \right] \tag{4}$$

Results and Discussion

Distribution of Respondents by Personal Characteristics

Age is generally believed to be an important factor in farming activities. This is because younger farmers are believed to commit more energy into production activities, while older ones are likely to be more experienced which may also impact positively on their productivity. As shown in the Table 2, majority (79.70 %) of the respondents were between the economically active age of 31–60 years with a mean age of 45.7 years. With respect to gender of surveyed respondents, 81.08 % of the respondents were males, while only 18.92 % of the respondents were females showing that arable crop farming in the study area was more popular

Table 2 Description of respondents by personal characteristics

Personal characteristics	Frequency	Percentage	Mean
Age (years) of respondents			
30 or less	20	13.51	
31–40	26	17.57	
41–50	48	32.43	47.5
51–60	44	29.73	
Above 60	10	6.76	
Gender of respondents			
Male	120	81.08	
Female	28	18.92	
Marital status			
Married	128	86.49	
Single	10	6.76	
Divorced	4	2.70	
Widow	6	4.05	
Religion			
Islam	55	37.16	
Christianity	90	60.81	
Traditional worshipper	3	2.03	
Educational level			
No formal education	54	36.49	
Adult literacy training	4	2.70	
Primary education	45	30.41	
Secondary education	29	19.59	
Technical/vocational education	5	3.38	
Tertiary education	11	7.43	
Secondary occupation income			
0 or less	90	60.81	
5,000–20,000	30	20.27	
21,000–40,000	16	10.81	
41,000–80,000	5	3.38	26,387
81,000–150,000	3	2.03	
150,000–400,000	2	1.35	
401,000 and above	2	1.35	

Source: Field survey, 2010

among the males. Furthermore, most (86.49 %) of the respondents were married. Majority (60.81 %) of the respondents were Christians, while 37.16 % of the respondents were Muslims. Traditional worshippers constituted 2.03 % of the respondents.

In terms of education, 36.49 % of the respondents had no formal education, 30.41 % were educated up to the primary school level, and 19.59 % up to secondary school level. Only 7.43 % of the respondents have tertiary education. This suggests a reasonable level of literacy among the respondents. From Table 4, about 43.92 %

of the sampled respondents have secondary occupation, while the remaining 56.08 % do not have. The secondary occupation included mainly artisanship, trading, carpentry, hunting, and cattle rearing, among others. Furthermore, 86.49 % of the respondents had extension contact, while the remaining 13.51 % do not have. This implies that the farmers would have access to regular update of improved farming technologies which is likely to boost their productivity. Out of this, 86.49 %, majority (72.3 %) of the respondents had up to 12 times of extension contact in the last production season, while the mean contact frequency is 11 times in the last production season.

The study further showed that 82.43 % of the respondents had no access to credit facilities. This may limit the ability of the farmers to expand their scale of production. This lack of access to credit facilities may be due to high interest rates being charged by financial institutions, and other bureaucratic bottlenecks which always characterize loan acquisition and disbursement in the country, in general.

The distribution of respondents by household size is also shown in Tables 2 and 3. From the table, 52.03 % of the respondents had between 1 and 4 household members, while 27.07 % have household size of between 10 and 14 members. The mean household size for the sampled respondents is approximately eight persons, implying that other members of the household can provide family labor in agricultural production. This could however lead to the use of child labor at the expense of formal education.

It is obvious from Table 3 that 65.54 % of the respondent cultivated less than 1 ha of farmland and 10.81 % cultivated between 1.101 and 1.5 ha of farmland, while 13.51 % cultivated between 1.50 and 2.0 ha of farmland. This corroborates the true picture of subsistence nature of arable crop farming in Nigeria. The mean land size cultivated by the respondents' was approximately 1 ha. The table also revealed that the predominant crop types grown by the arable crop farmers was maize, followed by cassava and vegetables, while other crop types grown included rice melon and pepper.

Distribution of Respondents by Adaptation Strategies to Climate Change

As indicated in Fig. 1, targeting rains to plant (leading to either early or late planting) was the most commonly (45.95 %) adopted strategy to reduce the effect of climate change. Use of irrigation coupled with construction of proper drainage channels as well as wetland farming was the least practiced (8.11 %) adaptation strategy among the major adaptation methods identified among arable crop farmers interviewed for the study. Targeting rains for planting as an adaptation strategy by the farmers was not surprising giving the inherent nature of peasant farmers as they rely on natural weather conditions for crop production. Furthermore, the limited use of irrigation coupled with construction of proper drainage channels as well as wetland farming, was due to the resource-poor nature of the farmers in the study

Table 3 Description of respondents by production characteristics

Extension contact			
0 or less	20	13.51	
1–6	40	27.03	
7–12	47	31.76	10.89
13–18	11	7.43	
19–25	20	13.51	
Above 25	10	6.76	
Household size			
1–4	23	15.54	
5–9	77	52.03	8.1
10–14	41	27.70	
Above 15	7	4.73	
Land size group			
0.5 ha or less	47	31.76	
0.501–1 ha	50	33.78	
1.01–1.5 ha	16	10.81	1.11
1.501–2 ha	20	13.51	
2.01–2.5 ha	2	1.35	
Above 2.5 ha	13	8.78	
Crop types grown			
Vegetables	51	34.5	
Cassava	123	83.1	
Maize	133	89.9	
Pepper/tomato/okra	15	10.2	
Yam	10	6.8	
Garden egg/potato/beans	3	2.0	
Rice	20	13.5	
Melon	14	9.5	

Source: Field survey, 2010

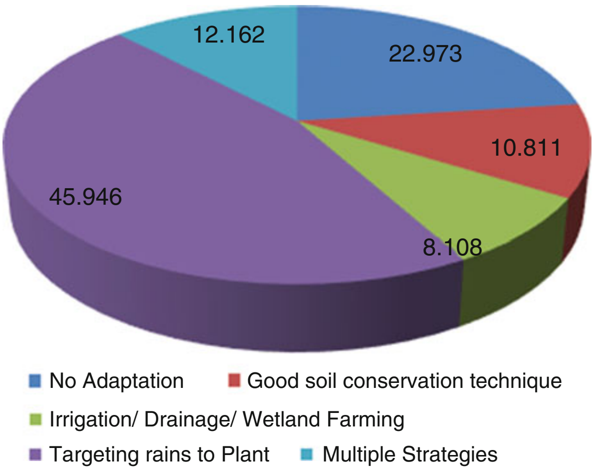

Fig. 1 Distribution of respondents by adaptation strategies to climate change

area. Moreover, 10.81 % of the respondents adopted good soil conservation techniques (such as planting cover crops, mulching) as a strategy in this respect, while only 12.16 % of the respondents engaged in multiple strategies to combat climate change. It was, however, interesting to note that 22.97 % of the arable farmers reported that they have not used any adaptation strategy.

Determinants of Arable Crop Farmers' Decisions on Climate Change Adaptation Strategies

Multinomial logit model was used in this study to estimate the determinants of respondents' adaptation behavior to climate change in the study area. Eight adaptation strategies were practiced by the sampled respondents in the study area. These are:

1. Good cultural practices such as mulching and resupplying of seedlings
2. Planting cover crops
3. Irrigation of farmland
4. Construction of proper drainage channels
5. Wetland/Fadama farming
6. Targeting rainfall to plant, leading to either early or late planting
7. Praying for God's intervention
8. No adaptation

For the purpose of analysis using multinomial logit, these adaptation strategies were restructured by grouping closely related choices together in the same category. Good cultural practices and planting of cover crops were grouped in the same category labeled as "good soil conservation techniques," while irrigation of farmland, construction of proper drainage channels, and wetland farming were grouped and labeled as "irrigation/drainage/wetland farming" category. The third category is "targeting rains to plant," followed by "multiple strategies" category which is a series of combination of the first three categories. Lastly, the fifth category is a combination of praying for God's intervention and no adaptation, and it is labeled "no adaptation."

Accordingly, the choice set in the restructured multinomial logit model included the following adaptation options:

1. Good soil conservation techniques
2. Irrigation/drainage/wetland farming
3. Targeting rains to plant
4. Multiple strategies
5. No adaptation

In this analysis, the last category (no adaptation) was used as the "reference state." Thus, results obtained from the multinomial logit analysis were in reference to no adaptation, and the result is presented in Table 4.

Table 4 Determinants of adaptation behavior of respondents'

Variables	Good soil conservation technique		Irrigation/drainage/wetland farming		Targeting rains to plant		Multiple strategies	
	Parameter	Odd-ratio	Parameter	Odd-ratio	Parameter	Odd-ratio	Parameter	Odd-ratio
Intercept	−21.98 (6942.07)	–	−4.25 (6277.93)	–	29.99 (3731.61)	–	−23.09 (6528.41)	–
Farming experience in years	−0.04 (0.05)	0.96	0.09 (0.07)	1.09	−0.02 (0.04)	0.98	−0.02 (0.05)	0.98
Educational level	0.08 (0.31)	1.08	0.57[c] (0.44)	1.78	0.14 (0.21)	1.15	0.77[a] (0.31)	2.17
Age	0.05 (0.06)	1.05	−0.02 (0.06)	0.98	0.00 (0.03)	1.00	0.03 (0.04)	1.03
Household size	−0.35[b] (0.17)	0.70	−0.32 (0.18)	0.72	−0.12 (0.09)	0.88	−0.17 (0.12)	0.84
Years of residence	0.07[b] (0.03)	1.08	0.09[b] (0.05)	1.09	0.03 (0.02)	1.03	0.03 (0.03)	1.04
Secondary occupation income	0.00[b] (0.00)	1.00	0.00 (0.00)	1.00	0.00 (0.00)	1.00	0.00 (0.00)	1.00
Extension contact frequency	0.15[a] (0.06)	1.16	−0.06 (0.09)	0.94	0.13[a] (0.05)	1.14	0.12[b] (0.06)	1.12
Respondent is a male	−0.60 (1.34)	0.55	−2.30[c] (1.45)	0.10	−1.28[c] (0.86)	0.28	−0.49 (1.13)	0.61
Respondent is a female	0.00 –	–	0.00 –	–	0.00 –	–	0.00 –	–
Respondent is married	1.36 (3934.40)	3.89	−15.15 (2941.33)	0.00	−14.58 (2941.33)	0.00	1.79 (5142.36)	5.98
Respondent is single	2.65 (3934.40)	14.10	−14.38 (2941.33)	0.00	−13.53 (2941.33)	0.00	1.61 (5142.36)	5.00
Respondent is divorced	1.75 (3934.40)	5.73	−31.79 (4387.86)	0.00	−15.59 (2941.33)	0.00	2.59 (5142.36)	13.31

Respondent is widowed	0.00 –	–	0.00 –	–	0.00 –	–	0.00 –	
Respondent is a Muslim	0.09 (4049.14)	0.92	−0.70 (3862.53)	0.50	−15.24 (2296.42)	0.00	1.48[c] (0.78)	4.41
Respondent is a Christian	0.17 (4049.14)	1.18	−1.45 (3862.53)	0.23	−16.12 (2296.42)	0.00	−0.12 (0.00)	0.88
Respondent is a traditional worshipper	0.00 –	–	0.00 –	–	0.00 –	–	0.00 –	–
Land size of 1 ha or less	12.86 (4039.47)	384785.82	20.92 (3980.19)	1219116463.91	0.78 (1.59)	2.17	17.51 (4021.98)	40328369.50
Land size of 1.01–1.5 ha	17.91 (4039.47)	59722836.13	17.27 (3980.19)	31727484.63	1.38 (1.42)	3.99	17.30 (4021.98)	32638405.51
Land size of 1.501–2 ha	17.60 (4039.47)	43947663.81	18.41 (3980.19)	98786329.21	2.02 (1.50)	7.53	17.14 (4021.98)	27827995.26
Land size of 2.01 to 2.5 ha	18.97 (4039.47)	173140484.39	19.08 (3980.19)	193586592.25	1.83 (1.67)	6.25	2.58 (4391.45)	13.19
Land size of above 2.5 ha	0.00 –	–	0.00 –	–	0.00 –	–	0.00 –	–
Credit access	1.65[c] (1.01)	5.21	−0.26 (1.54)	0.77	0.62 (0.77)	1.85	1.01 (1.02)	2 .74
No credit access	0.00 –	–	0.00 –	–	0.00 –	–	0.00 –	–

Source: computed from survey data; 2010
Standard errors are in parenthesis
[a]Coefficients significant at 1 %
[b]Coefficient significant at 5 %
[c]Coefficient significant at 10 % chi-square of log likelihood = 117.76[a]

The result revealed that explanatory variables in the model significantly explain the determinants of adaptation behavior of respondents to climate change in the study area. The chi-square value of 117.76 associated with the log likelihood ratio was significant ($p < 0.01$) suggesting strong explanatory power of the model. The study found out that household size is significant ($p < 0.05$) but negative, implying that an increase in household size will decrease the probability of respondents' choosing good soil conservation techniques such as good cultural practices and planting cover crops as an adaptation option. Also, the odds of choosing good soil conservation adaptation option as opposed to not adapting at all is 0.70 (70 %) per unit decrease in household size.

The coefficient of number of years of residence in a community is also significant ($p < 0.05$) and positive both for "good soil conservation techniques" and "irrigation/drainage/wetland farming," implying that an increase in this variable will increase the probability that the respondents will choose each of these adaptation options, respectively. This is because with increase in the years of residence of an individual in the community, there is higher possibility of an individual having access to more social capital in the community, thus aiding his ability to adopt new innovations to improve his farming activities and livelihood in general. In the same vein, the odds of adopting each of these strategies by the respondents compared to not adopting at all are 1.08 and 1.09, respectively, for each of the adaptation strategies mentioned above. Moreover, coefficient of income from secondary occupation was also found to be significant ($p < 0.05$) and positive for the adaptation strategy of good soil conservation technique, implying that a change in income from secondary occupation will likely cause an increase in the respondent's behavior towards choosing this adaptation strategy. This is because wealthier households are likely to be willing to adapt by investing in good soil conservation techniques. This follows the view of Knowler and Bradshaw (2007) that the adoption of agricultural technologies requires sufficient financial well-being. Thus, expanding smallholder farmers' access to off-farm sources of income increases the probability that they will invest in good farm practices. The associated odd of respondents adopting this strategy compared to the reference category for each unit increase in income from secondary occupation is 1.00.

Coefficient of educational level of respondent was also found to be significant ($p < 0.10$) and positive for strategies of irrigation/drainage/wetland farming and multiple strategies, implying that an increase in this variable will increase the likelihood of sampled respondents choosing these strategies, with associated odd values of 1.78 and 2.17, respectively . Generally, higher level of education is believed to be associated with access to information on improved technologies and productivity consequences as evidence from various sources indicates that there is a positive relationship between the education level of the household head and the adoption of improved technologies and adaptation to climate change (Maddison 2006). Therefore, farmers with higher levels of education are more likely to better adapt to climate change by taking up multiple strategies.

Furthermore, the coefficient of frequency of extension contact was found to be significant and positive, for strategies of good soil conservation techniques

($p < 0.01$), targeting rains to plant ($p < 0.01$), and for multiple strategies ($p < 0.05$) implying that an increase in this variable will increase the likelihood of sampled respondents choosing these strategies, respectively. The associated odd values of choosing the strategies by respondents as opposed to not adapting at all are 1.16, 1.14, and 1.12, respectively. With these in mind, farmers who have access to extension services are more likely to be abreast of information on changing climatic conditions and the various management practices they can use to adapt to these changes. In terms of credit access, the result revealed that this variable is significant ($p < 0.10$) and positively affects adaptation behaviors of respondent to good soil conservation techniques, with an associated odd value of 5.21 per unit increase in access to credit facility. From the table, an increase in the number of respondents having credit access will increase the likelihood of this adaptation. This is true because poverty or lack of financial resources is one of the main constraints to adjusting to climate change.

The result further shows that the dummy variable representing religious beliefs of the respondents is in favour of those practicing Islam, despite majority (60.81 %) of the sampled respondents' being Christians. Religion is significant ($p < 0.10$), and positively affecting adaptation behaviors of respondent to taking multiple adaptation strategies with an associated odd value of 4.41 per unit increase in this variable. This implies that farmers who are Muslims show positive disposition towards using multiple adaptation strategies towards combating climate change. In the same vein, the analysis result of gender, which is also a dummy variable in this model, is in favor of the males given the fact that the males constituted 81.08 % of the respondents, while the females constituted 18.92 % of the respondents. Gender is significant ($p < 0.10$) and negatively affecting adaptation behaviors of respondent to irrigation/drainage/wetland farming as well as targeting rains to plant, each with associated odd values of 0.10 and 0.28, respectively, per unit increase in number of male respondents. From the table, as male respondents increase, there is likelihood of decrease in taking up these adaptation options.

Conclusion and Recommendations

This study establishes the fact that arable farmers adapt to climate change situation in their local settings. The multinomial logit results clearly emphasized that household size and gender in favor of the males negatively influenced adaptation behaviors to climate change. On the other hand, years of residence in a community, educational level, frequency of extension contact, access to agricultural credit, married respondents, and income from secondary occupation are variables which engender positive adaptation behaviors of respondents to climate change. From the foregoing, the study recommends that:

Policies from government and other stakeholders should ensure that farmers have access to sufficient credit; this will increase their ability and flexibility to change production strategies in response to the harsh forecasted climate conditions.

There should also be investment on yield increasing technology packages to increase farm income.

Also, there should be encouragement of informal social networks among farmers and in rural communities as it has the potentials of increasing social capital useful for adaptation.

Farmers should be encouraged to acquire formal education as it has the likelihood of increasing the possibility of responding to positively to adaptation strategies against climatic change. Allied to this is the need for increased access to extension services by farmers in order to educate farmers more and disseminate useful agricultural innovations that will improve living agricultural production in the face of changing weather condition while also improving the standard of living of the farmers.

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Assessing How Participatory/Community-Based Natural Resource Management Initiatives Contribute to Climate Change Adaptation in Ethiopia

Hannah Reid and Lucy Faulkner

Contents

Abstract

This chapter assesses the role of community-based/participatory natural resource management (CB/PNRM) in supporting adaptation to current and potential future climate change impacts among pastoral communities in Ethiopia. Such communities are expected to experience significant changes in the natural environments on which their livelihoods rely. Climate impacts are set to exacerbate and intensify an existing dynamic risk landscape characterized by persistent poverty, social and political marginalization, land degradation, and conflict largely due to policy and governance failures undermining dryland productivity. Present pastoralist coping

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capacities are not sufficient to cope with existing recurrent drought periods and other climate variability impacts, with climate change risk factors likely rendering traditional coping strategies unsustainable. In response, this chapter focuses on selected CB/PNRM initiatives undertaken by Save the Children to show the value of CB/PNRM as an adaptation strategy that builds climate resilience and delivers adaptation benefits for targeted pastoralists/agropastoralists. While climate change was not a specific focus of development investment design, important contributions to strengthening local adaptive capacity through the implementation of transformative processes and practice have been made. This suggests that newer fields of study such as community-based adaptation can learn from older disciplines such as CB/PNRM, with the potential role that development actors can play in the context of building climate resilience meriting further attention among governments and policymakers. Drawing on the development of bespoke methodology for monitoring and evaluating effective adaptation, this chapter also contributes to adaptation evaluation knowledge.

Keywords

Climate change • Drought • East Africa • Ethiopia • Pastoralists • Agropastoralists • Participatory natural resource management • Community-based natural resource management • Community-based adaptation • Adaptive capacity • Resilience • Transformation • Monitoring and evaluation

Introduction

Many pastoralist communities in East Africa experience persistent poverty, social and political marginalization, land degradation, and conflict (although experiences vary widely both within and between pastoral groups and pastoral areas). These are due to failures of policy and governance rather than the pastoral system itself. Pastoralism is often (wrongly) viewed as economically inefficient and environmentally destructive despite evidence that it often brings economic and environmental benefits beyond those achieved by alternative land uses such as ranching. In addition, the pastoralist way of life is often more resilient to changing climatic conditions because over the years pastoralists have developed strategies to cope with difficult conditions (Riché et al. 2009). In many instances, pastoralists are able to positively exploit greater climate variability to increase their resilience and generate higher returns than would be the case if the environment/climate were more stable or predictable (Krätli and Schareika 2010; Hesse 2010). This is because pastoral systems often have institutions and strategies that can harness the ephemeral, variable, and unpredictable distribution of resources (particularly highly nutritious pastures) to their advantage. This in turn contributes to greater accumulation of assets, better diets, and more income – in other words a more resilient community. Well-functioning pastoral systems can also often cope better with periodic extreme events such as drought when compared with institutions and strategies better suited to managing more stable resources. This is because they reduce the loss of assets and have a greater capacity to "bounce back" and resume high productivity once the extreme event is over (Ced Hesse personal communication, Nov. 2012).

Climate change is predicted to have severe impacts in East Africa. While some of these impacts will be positive, including bringing more rainfall to certain dry areas, most are likely to be negative. The natural environments on which many of the poorest rely are expected to experience significant changes. Sound risk management to increase livelihood resilience and maintain ecosystem services can be an important component of a cost-effective approach to help people adapt to climate change, especially the most vulnerable groups, including women and children (Ambani and Nicholles 2012).

While most development interventions are not designed with climate change adaptation as a key objective, it is likely that they influence community capacity to adapt to changing shocks and trends – whether as a result of climate change or other pressures associated with development (Jones et al. 2010). There is the potential for "double dividends" resulting from adaptation and development interventions due to the strong synergies between the two (Ambani and Nicholles 2012). There is also a growing appreciation that newer fields of study, such as community-based adaptation, have much in common with older disciplines such as CB/PNRM and can both learn and adopt many principles from this older field of study (Chishakwe et al. 2012; Munroe et al. 2011). Research that assesses the role of CB/PNRM interventions in adaptation, however, are in short supply, and evidence of these "double dividends" is mostly anecdotal.

This chapter aims, in part, to help fill this information gap by conducting a more rigorous assessment of the contribution that selected Save the Children CB/PNRM initiatives have in contributing to climate change adaptation through building climate resilience and delivering adaptation benefits to the poorest and most marginalized pastoralists and agropastoralists. This includes details of the bespoke methodology developed to achieve this goal and the results and recommendations generated from applying this methodology at the study sites.

Study Site Profiles

Selected Save the Children CB/PNRM interventions are located in Liben, Gordola, and Arero districts ("woredas") in the lowlands of Borana and Guji Zones of Oromia Regional State in Ethiopia (Fig. 1). Similar sites in Horbtor Kebele, Yabello District, with the same history of preexisting development and humanitarian initiatives, but no Save the Children CB/PNRM interventions, were also visited for comparative purposes. Both study sites experienced droughts in 2011, which is the primary climate-related hazard (Riché et al. 2009).

Study sites are predominantly arid and semiarid rangelands dominated by tropical savannah vegetation with open grassland and perennial woody vegetation. People are primarily pastoralists with cattle, sheep, goats, and camels, or agropastoralists cultivating maize, teff, sorghum, and haricot beans (Riché et al. 2009). Average annual rainfall

Fig. 1 Oromia Regional State showing the Borana Region in the south and the study sites in this region

ranges between 350 and 900 mm, with considerable spatial and temporal variability in quantities and distribution. Rainfall usually occurs from March to May and September to November. Average annual temperature ranges between 19 °C and 26 °C.

Ethiopia is considered one of the most vulnerable countries to the impacts of climate change (World Bank 2010; Adem and Bewket 2011). Potential climate change impacts in the study sites are increasing temperatures and changing rainfall patterns, with study sites located in medium and high drought probability zones (NAPA 2007). Mean annual temperature increases of 1 °C, 1.8 °C, and 2.9 °C by 2030, 2050, and 2080, respectively, are expected compared to 1961–1990 levels (NAPA 2007). Existing trends in increased hot days and hot nights and decreasing annual cold days are set to continue (Conway et al. 2007; Levine et al. 2011). Precipitation patterns are less certain with discrepancies between climate models on modest increases or reductions in rainfall (Conway et al. 2007; NAPA 2007). Similarly, Ethiopia's exposure to drought and floods is heavily influenced by the El Niño/La Niña phenomena, and the impacts of climate change on these phenomena are currently unclear (ACCRA 2012). Models are, however, broadly consistent in suggesting that rainfall across the study sites will fall more in heavy events (McSweeney et al. 2007). Likewise, local and scientific observations are consistent with drought frequency increasing from every 6–8 years to every 1–2 years (Riché et al. 2009).

These climate changes however form only part of the study sites' vulnerability landscape (McDowell 2011). Changes in non-climate contextual trends regarding livelihood and resource needs have contributed to reducing pastoralist resilience over time. This includes a reduction in natural resource and rangeland availability, especially to key dry season grazing areas due to commercial farming and increasing population pressures resulting in a constant flow of people moving from highland areas to lowlands in search of productive natural resource assets for livelihood sustainability. Pastoralist communities themselves have also increased in number, contributing to an overall increase in human population size. Widespread bush encroachment has increased pressures on reduced rangeland resources, and changes in government regional administrative boundaries between Oromia and Somali states have resulted in many Boran and Guji pastoralists losing previously available land. Furthermore, increasing state government administrative influence at local community level has resulted in reduced power and influence yielded by traditional customary institutional leaders. This shift has seen traditional pastoralist processes ignored by formal administrative bodies who provide legal backing and policy support to permanent settlements and farming, therefore reducing access to, for example, existing migration routes and water points that are key to pastoralist livelihoods. Additional changing trends of increased social and economic differentiation combined with weakened indigenous safety net systems, resulting in smaller herd sizes per household with increasing poverty levels, have also contributed to increased livelihood vulnerability for pastoralist households.

In light of the above, although the future landscape of risk is uncertain, it is evident that climate change will provide an additional stressor for study site communities. Drought combined with extreme heat events is set to increasingly negatively affect the availability, productivity, and quality of pastures and farmland leading to negative consequences on household food and income levels and human and livestock health. With pastoralists identified as among those most vulnerable to climate change impacts (NAPA 2007), present coping capacities are not sufficient to cope with recurrent drought periods, including those of 2008 and 2010/2011 (Weiser 2012). Other impacts of current climate variability and poverty combined with climate change risk factors are set to render traditional coping strategies unsustainable (Adem and Bewket 2011; Venton et al. 2012).

Project Structure

Phase II of the Pastoral Livelihoods Initiative began in 2009 (Box 1 below), yet this study focuses on Save the Children's upgraded CB/PNRM work implemented under this initiative in 2012 (Box 2 below). Prior to 2009, Save the Children was engaged in the same CB/PNRM project sites where this study was conducted through phase I of the Pastoral Livelihoods Initiative (2004–2008), that focused on short-term drought response, child education, and health initiatives.

Box 1: The Pastoral Livelihoods Initiative (Stockton et al. 2012)
Phase II of the Pastoral Livelihoods Initiative is a US$16-million US-Aid-funded project implemented by Save the Children, CARE, Mercy Corps, and International Rescue Committee from 2009 to 2013 (Stockton et al. 2012). It aimed to improve pastoralist and ex-pastoralist livelihoods in the above study sites through a range of initiatives including:

1. Improving community-based natural resource management
2. Improving the ability of pastoralists to gain more economic value from their livestock
3. Diversifying their ability to generate income
4. Improving the effectiveness of early warning systems
5. Implementing selected interventions relating to maternal and child health and HIV/AIDS
6. Integrating drought response and recovery through crisis modifier mechanisms to protect livelihoods during drought periods

Box 2: Save the Children's Upgraded CB/PNRM Strategy
Overall goal: Enhanced community resilience to shocks, especially drought, through strengthening of pastoral livelihood systems and their resource management

Strategic objectives
1. Stronger stakeholder institutions, cooperation, and cohesion
2. Institutionalized, mutual learning for enhancing adaptive capacities and transformation
3. Improved land use (including secured assess) and sustainable NRM in the context of increasing climate variability

Measuring Adaptation Benefits

To assess the effectiveness of Save the Children CB/PNRM interventions in building resilience to climate change risk and delivering adaptation benefits for targeted pastoralists and agropastoralists, new methodology developed for the monitoring and evaluation of community-based adaptation (M&E for CBA) by research program Action Research on Community Adaptation in Bangladesh (ARCAB) is used. In line with current frameworks under development at the international level for successful adaptation M&E, this M&E for CBA system is universal in application and use and has been adopted for this study based on its rapid recognition and uptake by the international community.

The approach measures and evaluates the processes used and results obtained by Save the Children's CB/PNRM interventions in building *transformed resilience*. This means resilience is built at scale across the following three key components, resulting in climate vulnerable poor communities being able to successfully adapt to long-term uncertain future climate change impacts through sustainable adaptation strategies (Ayers and Faulkner 2012; Faulkner 2012b):

1. **Geographic scale**: Resilience is achieved beyond isolated development projects. Effective practice is mainstreamed into long-term institutional structures (scaled up), and activities are replicated beyond immediate project boundaries (scaled out).
2. **Time scale**: Resilience is sustainable, with communities continuing to maintain and build resilience after project activities have finished.
3. **Beyond business as usual approaches**: Resilience-building challenges existing development and DRR approaches and retargets efforts towards building the knowledge, capacity, and practice of vulnerable groups to longer-term climate and other risks, not just current risks. This requires using a climate lens to rethink the way existing development and DRR is done as part of the progression towards adaptation to climate change. It also requires refocusing how projectized development and DRR have been operationalized to date.

ARCAB describes the range of stakeholders and scales across which change needs to occur in order for the above to take place. These include the following: (1) the climate vulnerable poor, who are generally the poorest and most marginalized people in society (Smith et al. 2003); (2) the local formal and informal institutions needed to deliver adaptation services to these groups at the local level, including community-based organizations, local NGOs, and local government service delivery providers; and (3) the wider "community of practice" including national governments, international finance institutions and funds, and national and international learning forums such as the annual international community-based adaptation conferences.

Two components of this approach are used in this study. First, a framework for the identification of priority indicators to measure progress of Save the Children's CB/PNRM intervention towards *transformed resilience*. To realize this goal, the framework focuses on three domains of change:

(i) Meaningful and locally relevant **knowledge** (K) about climate change and adaptation science, and non-climate-related information, for the design of feasible, credible, and useful adaptation options.
(ii) Knowledge is not enough unless people and institutions have the **capacity** (C) to act on it. This means having the skills, power, and ability (including finances) to turn knowledge into practice. This applies in the context of both the individual, in terms of having access to the basic assets, resources, and

institutions that enable them to adapt to climate variability and change. It also applies to institutions that need access to resources and incentives to turn knowledge into action and the mandate to do this.

(iii) Supporting knowledge and capacity will lead to changes in **practice** (P). These can be adaptive strategies undertaken by local people or shifts towards a more integrated, long-term, flexible, strategic, and participatory way of development planning.

These domains are applied to the following outcome areas under which indicators are formed in light of climate and other risks identified as important at local level (Fig. 2 below):

- Indicators assessing the knowledge and capacity of climate vulnerable poor community stakeholders to improve their long-term adaptive capacity through the following prerequisites for adaptation: good development coupled with access to and ability to use information related to climate and non-climate risks
- Indicators assessing mainstreaming and institutional capacity to demonstrate if local institutions have the knowledge, capacity, and incentives to provide climate risk management and deliver adaptation benefits to climate vulnerable project participants
- Indicators of evidence that people and institutions are adapting to climate change risk through changing practice as a result of improved adaptive capacity and access to adaptation services

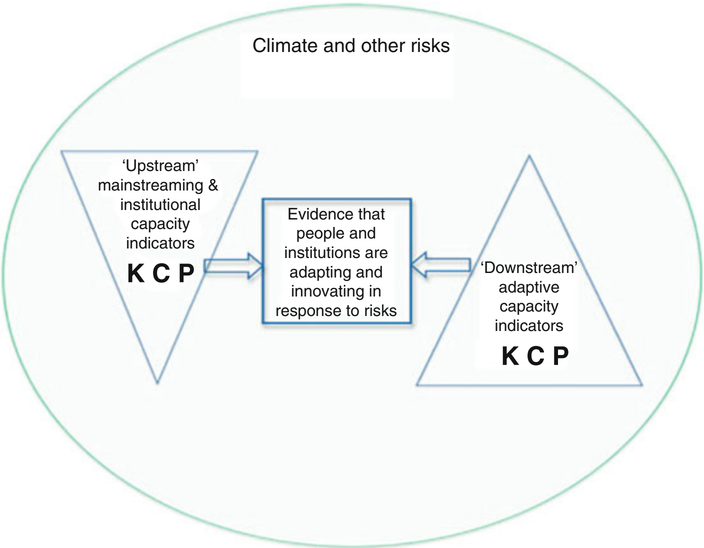

Fig. 2 Conceptual framework for outcome indicator areas used in the ARCAB M&E for CBA framework translated to fit Save the Children's CB/PNRM intervention (Ayers and Faulkner 2012; Faulkner 2012b) adapted from Brooks et al. 2011

Indicator choice for this study was guided by an extensive review of literature and external expert advice on the specifics of adaptation in the context of dryland pastoralist systems in Ethiopia and East Africa. In addition, strong collaboration with Save the Children staff ensured indicators were not only scientifically rigorous but also locally relevant, meaningful, and context specific (Ayers et al. 2012).

Data Collection in the Field

Mixed methods of data collection were employed. This consisted of predominantly qualitative but also quantitative measurements of evidence through focus group discussions (FGDs), key informant interviews, participant observation, and field notes. Households from different gender, wealth, age, and livelihood systems were selected based on random sampling. Where possible, research validity was strengthened through the triangulation of data sources. Supplementary secondary evidence was also collated during fieldwork to support information required for quantitative data analysis from Save the Children CB/PNRM project documents.

Analytical Framework Used

To aid analysis of field and desk-based research results, another component of the selected methodology was adapted: the CB/PNRM Resilience Scale (Fig. 3 below).

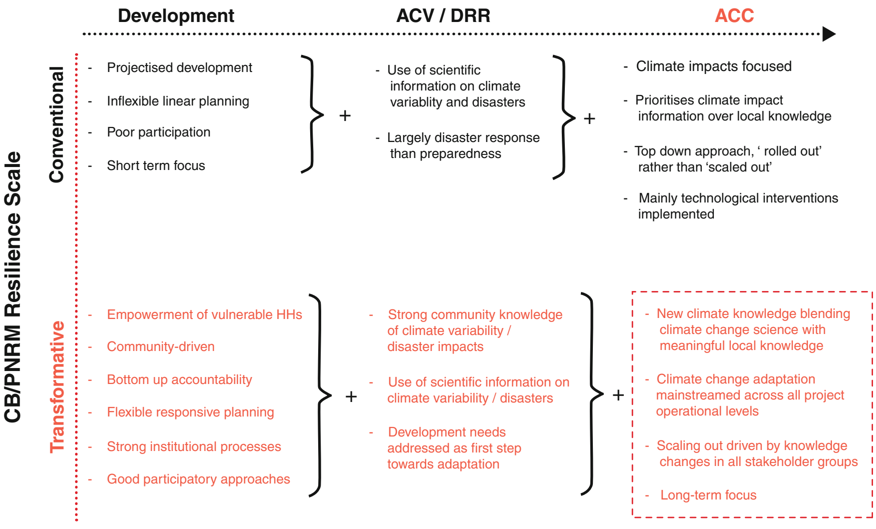

Fig. 3 An analytical framework for assessing CB/PNRM through a climate change lens – the CB/PNRM Resilience Scale (Faulkner 2012a)

The CB/PNRM Resilience Scale moves horizontally from development to adaptation to climate variability, including disaster risk reduction (ACV/DRR), to adaptation to climate change (ACC). Vertically, the scale moves from *conventional* approaches to development, ACV/DRR and ACC, to those that are *transformative*. To move towards "transformed resilience," progress towards the bottom right-hand box is recommended: "transformative ACC."

To move towards this goal, changing the methods undertaken and approaches used under what is classed conventional development and ACV/DRR in Fig. 3 above is required. This includes:

- Revisiting conventional development and ensuring that the basic needs of the poorest and most marginalized people vulnerable to climate change are being addressed
- Empowering climate vulnerable poor groups to ensure that their knowledge and demands are reflected in decision-making processes
- Moving beyond short-term projectized approaches to planning towards integrated approaches that engage with and build the capacity of local to national institutions, with associated sustainable institutional and resource bases
- Creating spaces for knowledge sharing and knowledge transfer, to support the scaling up and scaling out of effective processes and practice
- Ensuring flexible approaches to planning that can respond to changing needs and incorporate a range of knowledge bases, especially that generated by ultimate project participants.

Moving towards transformative ACC is largely driven by the integration of *new knowledge about adaptation and future climate change*. This knowledge is coproduced from both improved scientific information about future climate change impacts and adaptation science and locally generated knowledge from the climate vulnerable poor about past climate trends and the interaction between climate impacts, vulnerability, and adaptation. This blending of scientific and local knowledge is transformational, because it forces development practitioners to rethink the way development planning and implementation are undertaken. Scientific information specifies that climate impacts are becoming more uncertain; hence, a lens that provides more dependable information on possible outcomes at the local scale is needed in order to understand what matters to local people. Relying solely on scientific expertise is not enough. Local knowledge is also needed to develop a new kind of knowledge that all stakeholders can use in practice.

However, moving towards transformative ACC is not just about new climate change information and adaptation science. It also requires transformative development and transformative ACV/DRR approaches to be operationalized (along with associated transformations in attitudes, skills, and actions) to support moving towards this goal. This is shown on the scale by the addition signs (+). Transformative ACC requires transformative development, *plus* transformative ACV/DRR approaches, and *plus* other components that may be required. This is particularly important for this assessment, where project activities were not initiated with improving climate change resilience as a key goal – and yet many of the development-oriented interventions implemented will likely still make important contributions to transformed climate change resilience.

Similarly, making the distinction between conventional and transformative ACC is important, because moving towards more sustainable and transformative resilience does not advocate undertaking *any* adaptation measures. Adaptation interventions can be viewed on a continuum ranging from specific climate change impacts-based approaches to those that view adaptation *as* development (Ayers and Dodman 2010; McGray et al. 2007). On the CB/PNRM Resilience Scale in Fig. 3 above, conventional ACC takes the former approach where climate change impacts such as droughts or floods are taken as the starting point for vulnerability assessments, giving rise to largely technological adaptation solutions through a top-down approach such as insurance schemes for livestock losses. In comparison, transformative ACC takes the latter approach that views adaptation as increasing the adaptive capacity of people to climate and non-climate risk by taking a livelihoods-based view to assessing vulnerability. Consequently, this results in adaptation interventions that target the underlying drivers of vulnerability as specified by climate vulnerable poor groups themselves, such as improved household access to safe water sources. This perspective is important in the context of this assessment where confidence in what to expect in terms of specific climate change related impacts for project sites in the coming years is not high.

Results and Analysis of CB/PNRM Effectiveness Through a Climate Change Lens

The following results and analysis of Save the Children's CB/PNRM intervention have been made to provide insight into how much it contributes to building resilience to current and potential future climate change impacts and delivers adaptation benefits for targeted pastoralists and agropastoralists. For ease of comparison, results are summarized alongside those from the non-Save the Children intervention site in Table 1 below. Discussion and analysis of results follows, including examples of key differences between research study sites and justifications to support why results are placed in each position on the CB/PNRM Resilience Scale in Figs. 4 (Save the Children site) and 5 (non-Save the Children site) below.

Save the Children's CB/PNRM Intervention

1. **Awareness of, access to, and integration of weather and seasonal forecasts in planning and decision-making processes at community and local institutional level**

   Community and local institutional stakeholders have access to up-to-date weather and seasonal forecasts from a mix of traditional and more scientific sources. These are harmonized at community scale to respond to local needs

Table 1 Fieldwork results comparing resilience-building outcomes of Save the Children's CB/PNRM intervention site with the non-Save the Children site

Results from Save the Children's CB/PNRM intervention site	Results from the non-Save the Children site
1. Awareness of, access to, and integration of weather and seasonal forecasts in planning and decision-making processes at community and local institutional level	Lack of access to and integration of short-term weather and longer-term climate information in planning and decision-making processes at community level, but understanding of need for longer-term climate information to support community preparedness measures to increasing drought risk
2. Shift from seasonal planning to more forward-thinking longer-term foresight, including community perceptions of increased ability to cope with and adapt to future drought conditions	Lack of long-term, forward-thinking foresight in planning processes including ability to trade off possible futures and consequences given uncertainty
3. District government engagement supporting revitalization and potential sustainability of upgraded traditional pastoralist rangeland management systems	Good relationship with local government institutions offering community support with rangeland management through by-law enforcement
4. Implementation of new and improved livelihood and rangeland management practices increasing respondent knowledge and capacity skills sets leading to improved livelihood outcomes, land productivity, and biodiversity	Implementation of existing livelihood and land use strategies despite perceived climate variability changes to local context leading to reduced livelihood outcomes, land productivity, and biodiversity
5. Two-way knowledge exchange on NRM processes between local government and community facilitating improved practices in a climate variability context	Lack of community access to new and improved information and capacity bases required for alternate livelihood strategies, improved rangeland management practices, and adaptation
6. Reducing development deficits through appropriate seasonal mobility and improved access to nutritious pasture, water sources, salt licks, and forest areas facilitating increase in wealth, livestock health, and food security	Appropriate seasonal mobility restricted due to reduced access to nutritious pasture and water sources in wet and dry seasons facilitating increased livelihood and livestock insecurity
7. Community perceptions of increased ability to cope with and adapt to future drought conditions including appropriate seasonal mobility and new knowledge and capacity to produce and store hay	Community perceptions of inability to cope with and adapt to current and future climate/drought conditions due to lack of access to new and improved knowledge and capacity bases required for adaptation
8. Increased female inclusiveness in decision-making processes across pastoralist institutional scales, including women empowerment with perceived ownership of and right to rangeland and natural resources coupled with shift in male mindset on cultural role and value of women	Male-orientated decision-making processes undertaken with lack of female inclusiveness and empowerment, but new understanding and insight into the beneficial role of women in NRM processes

(*continued*)

Table 1 (continued)

Results from Save the Children's CB/PNRM intervention site	Results from the non-Save the Children site
9. Utilization of participatory resource mapping and action plans supporting collective problem solving and consensus building, possible reduced conflict situations, and perceived system flexibility	Evidence of collective problem solving and consensus building through discussion within male community committee members
10. Community openness to test indigenous knowledge systems with external relevant information bases	Community openness to improve traditional NRM knowledge bases through expert information integration and learning-by-doing approaches
11. Responding to climate vulnerable poor needs through inclusivity respectful of pastoralist traditions, including benefit sharing mechanisms resulting in reduced livelihood vulnerability and improved coping capacity	Inclusion of poorer and more marginalized households in community planning with specified benefits and needs addressed unclear

and are used in planning and decision-making processes. Information is useful, yet access to comprehensive earlier weather forecasting is needed to strengthen community climate preparedness. Similarly, local institutional weather-related information provided is primarily short-term in focus, with weather information not the same as rigorous scientific information on longer-term climate change trends. As Save the Children's CB/PNRM intervention did not consider climate change from its outset, this weak integration of climate change foresight is unsurprising. Yet, to support project participants adapt to current and potential future climate changes, engaging with the scientific community to provide access to locally relevant and meaningful scientific and adaptation information is required. When integrated with local knowledge on vulnerability and adaptation, new knowledge is formed that can support changes in practice that lead to stronger resilience outcomes. It is not just *what* is being done that is important, but *why* and *with what knowledge* that is key. Undertaking practice that is not planned action based on climate change foresight reflects a coping paradigm compared to practice driven by new climate change knowledge. Consequently, this result is placed under *conventional ACV/DRR* on the CB/PNRM Resilience Scale in Fig. 4 below.

2. **Shift from seasonal planning to more forward-thinking longer-term foresight, including community perceptions of increased ability to cope with and adapt to future drought conditions**

   Although community climate change foresight is not strong, CB/PNRM planning processes have supported pastoralist and agropastoralist groups in shifting beyond the immediate confines of a seasonal planning approach towards a longer-term vision incorporating longer-term contextual trends. This includes the proper utilization of wet and dry season grazing areas and the systematic management of increasing herd mobility that promotes sustainability of key natural resources supporting improved capacity to adapt to

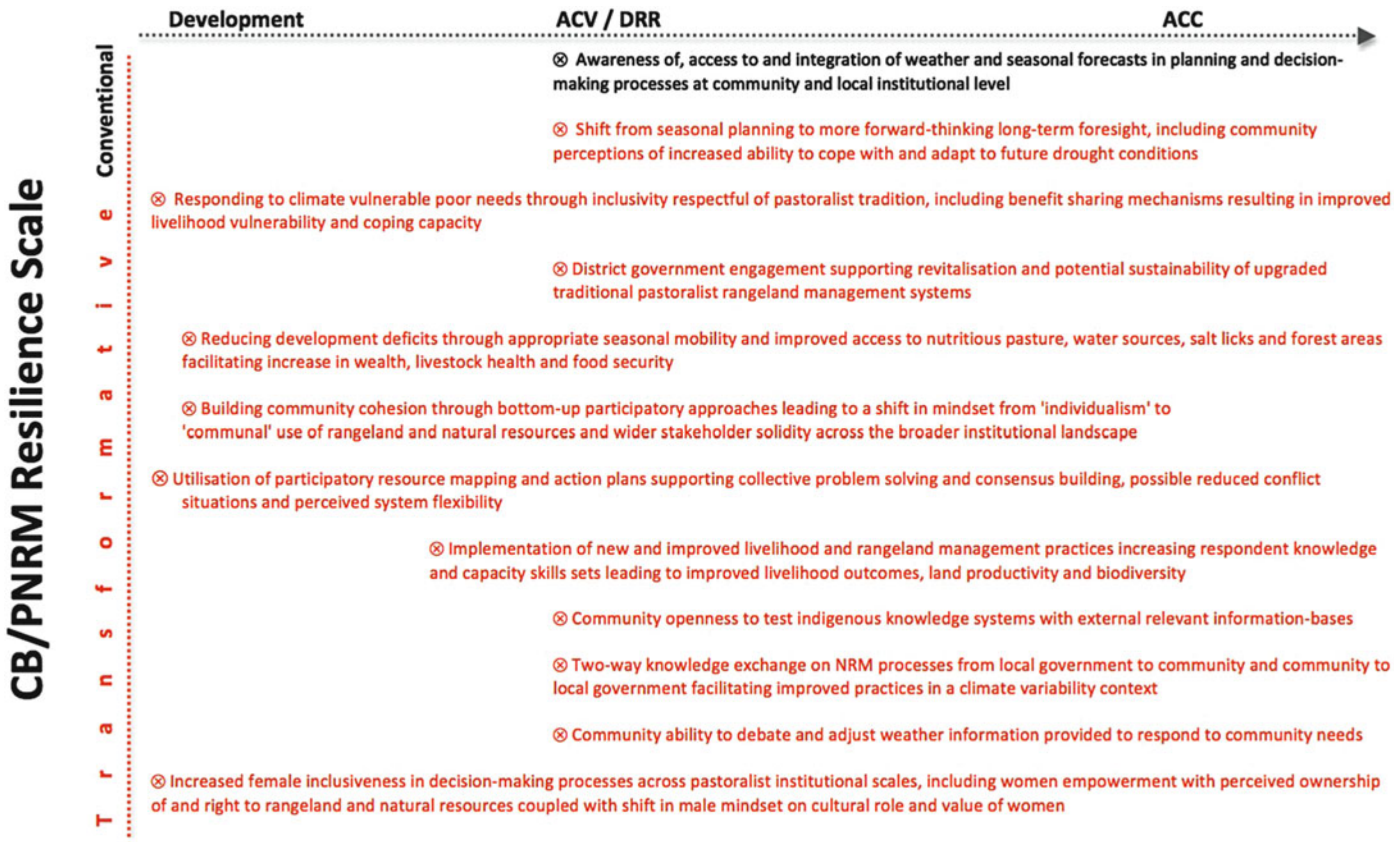

Fig. 4 Assessment of Save the Children's CB/PNRM intervention in building resilience to climate change risk for pastoralists and agropastoralists

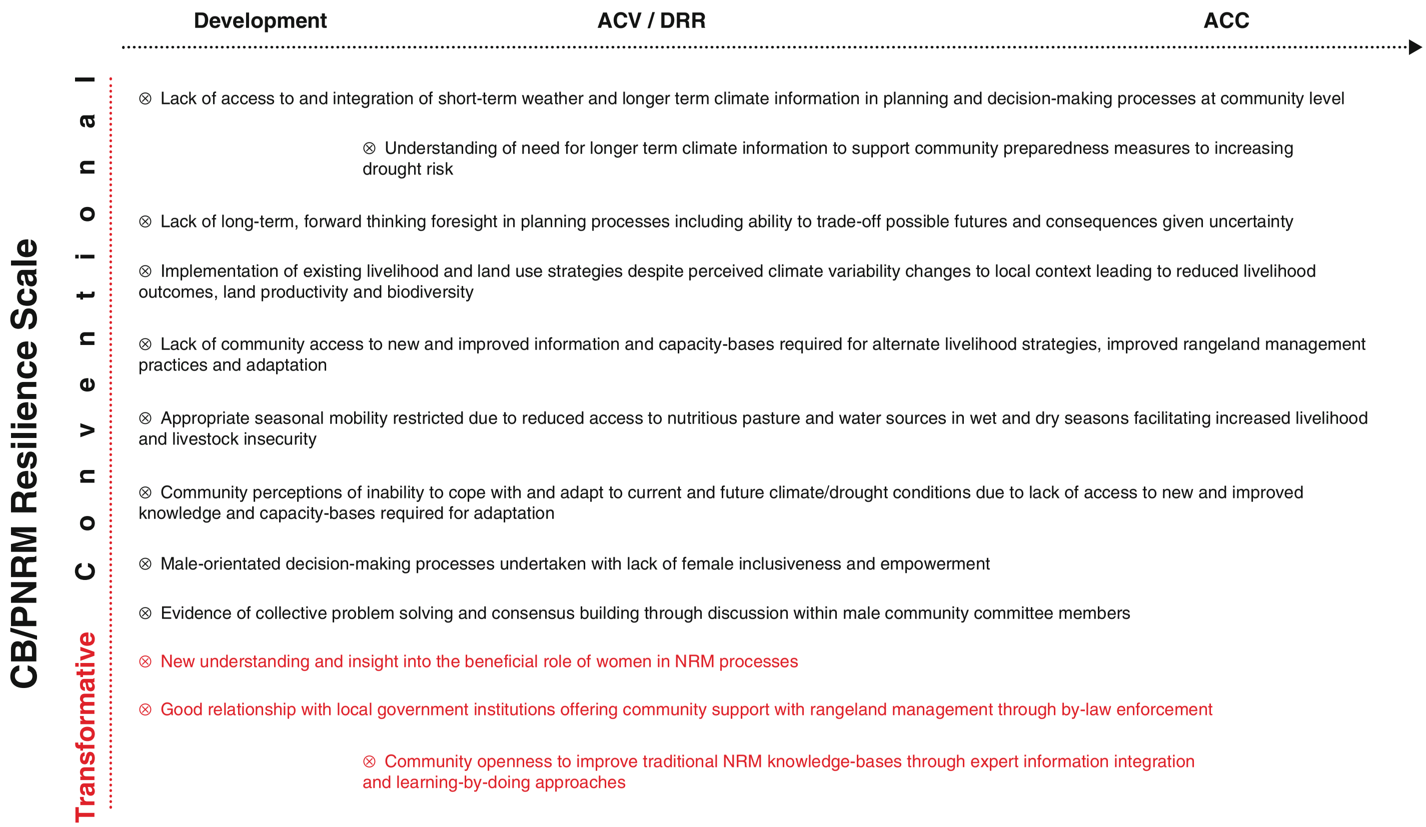

Fig. 5 Assessment of the non-Save the Children CB/PNRM intervention site in building resilience to climate change risk for pastoralists and agropastoralists

current climate variability impacts. This change in planning foresight is a strong entry point to build upon for adaptation to future climate change risk through the incorporation of locally meaningful scientific climate change information as discussed above. As a result, this evidence is placed under *transformative* on the CB/PNRM Resilience Scale. It is considered *ACV/DRR* as it supports community adaptation to current climate risk.

3. **District government engagement supporting revitalization and potential sustainability of upgraded traditional pastoralist rangeland management systems**

   Save the Children's CB/PNRM intervention has strengthened the existing relationship between relevant government departments, customary institutional leaders, and male and female community members – an important factor for adaptation. This includes government enforcement of traditional pastoralist rangeland management systems providing more secure access to and control over land and resources for community stakeholders. This strengthened government-community partnership signals a foundation for sustainability. Community stakeholders perceive they will reap benefits beyond initial project time boundaries. This is an important aspect of building resilience that moves beyond short-term projectized approaches to planning towards longer-term approaches that are integrated with key institutions for an enabling environment for adaptation. This evidence is *transformative* on the CB/PNRM Resilience Scale in Fig. 4 below, because it facilitates institutional processes that enhance longer-term access to resources communities require to adapt to climate and other risks. It is *ACV/DRR* because institutional engagement supports reduction of development deficits of community stakeholders as the first step towards adaptation. By improving access to the institutions and key assets people need to fulfill their basic capabilities, the ability of project participants to cope with and manage the additional stresses presented by climate variability and climate change are likely to be enhanced.

4. **Implementation of new and improved livelihood and rangeland management practices increasing community knowledge and capacity skill sets leading to improved livelihood outcomes**, **land productivity, and biodiversity management**

   Save the Children's CB/PNRM intervention provided community stakeholders with access to relevant and meaningful knowledge and capacity bases for the implementation of new and improved livelihood and NRM practices (examples in Table 2 below) that build resilience to current and potential future climate change impacts – *ACV/DRR* on the CB/PNRM Resilience Scale.

   Similarly, a learning-by-doing approach was undertaken, which is important in the context of adaptation, as not all future climate change impacts are known. Learning what works and what does not will need to be iterative as is discussed in further detail below. Likewise, evidence shows project participants view their surrounding ecosystem and its services in a holistic manner, rather than just as the provider of natural resources. Both these aspects form important components of resilience-building that are considered *transformative* on the CB/PNRM Resilience Scale.

Table 2 Examples of new and improved NRM-related knowledge, skills, and competencies for project participants under Save the Children's CB/PNRM intervention

Proficiency sets			
"Hard" asset oriented		"Soft" process oriented	
New	Improved	New	Improved
– Hay preservation and storage	– Selected bush clearing	– Participatory resource mapping	– Ability to organize wet/dry season grazing areas leading to herders and households undertaking appropriate seasonal mobility
– Debarking for bush clearing	– Soil/water conservation	– Shift in understanding from land and water being only perceived key resources to inclusion of forest capital (leading to forest protection)	– Ability to assign and reallocate appropriate settlement locations
– Aloe vera soap production	– Use of crop residue (for livestock fodder)		
	– Upgrading drought reserves for weak and lactating livestock		

5. **Two-way knowledge exchange on NRM processes between local government and community facilitating improved practices in a climate variability context**

   Local government stakeholders feel CB/PNRM fosters two-way knowledge exchange between government, customary institutional leaders, and community members on effective processes and practices. This merging of knowledge to create new knowledge is important. It suggests potential sustainability of CB/PNRM processes in light of changing contexts. "We can continue with PNRM because we have the knowledge, skills and capacity to manage resources effectively" (Deedha Customary Institution members). This improved capacity to combine local knowledge and "expert" scientific knowledge is important in the context of building resilience to climate change impacts as scientific predictions at a geographical and time scale that would help pastoralists plan livelihood activities accordingly are currently lacking and are not always in agreement with local knowledge of what has been experienced so far, and what changes local people feel are likely to be experienced in the future. This evidence is placed under *transformative ACV/DRR* on the CB/PNRM Resilience Scale. It is "transformative" based on the strong network between community respondents and local government and the corresponding two-way flow of knowledge sharing between these stakeholders. It is considered ACV/DRR because it results in improved respondent resilience and ability to adapt to climate variability risk. This result would move closer towards "transformative ACC" if knowledge sharing included the integration of longer-term scientific climate information with local vulnerability insights to form new knowledge required to support changes in planning and practice.

6. **Reducing development deficits through appropriate seasonal mobility and improved access to nutritious pasture**, **water sources**, **salt licks, and forest areas facilitating increases in wealth**, **livestock health, and food security**

   Evidence suggests that development capacity to cope with and respond to climate variability and environmental hazards has improved by ensuring that the basic needs of community stakeholders are addressed as a first step towards adaptation. Examples of this are presented in Table 3 below. Looking through a climate change lens on the CB/PNRM Resilience Scale, this result is considered *transformative development*.
7. The above evidence, together with new hay making skills, links to another result on the CB/PNRM Resilience Scale: **increased community perceptions of ability to cope with and adapt to drought conditions**.
8. **Increased female inclusiveness in decision-making processes across pastoralist institutional scales**, **including women empowerment with perceived ownership of and right to rangeland and natural resources coupled with shift in male mindset on cultural role and value of women**

   Female inclusiveness in CB/PNRM decision-making processes across pastoralist management system scales presents a considerable change in cultural values within the traditional male-orientated pastoralist system. "The past system is wrong. Women are equal in NRM. They know the problems we face so it's advantageous for us to have them as part of the process" (Aardha Customary Institution members). Female benefits include attending meetings to discuss and disseminate issues within the community and perceived increases in rights and empowerment. Community benefits include the provision of instrumental support with access to natural resources through active engagement in decision-making processes. This result moves beyond conventional towards *transformative development* on the CB/PNRM Resilience Scale in Fig. 4 below.
9. **Utilization of participatory resource mapping and action plans supporting collective problem solving and consensus building**, **possible reduced conflict situations and perceived system flexibility**

   Undertaking resource mapping has fostered collective problem solving and consensus building reflecting priorities of all rangeland users resulting in "reduced conflict through sharing and saving resources" (Reera Customary Institution members). In light of an uncertain future climate where potential demand and competition for natural resources and ecosystem services may increase, this outcome is important. Likewise, the participatory approach used provides perceived system flexibility, with community plans regularly monitored and changed if required. These results provide examples of *transformative development* processes on the CB/PNRM Resilience Scale that aid building climate resilience: community-driven responses; flexible planning approaches; empowerment of respondents through increasing knowledge and capacity bases; and the facilitation of spaces where people can unite to discuss, share, and generate meaningful information deemed important by them.

Table 3 Example results, short-term benefits, and outcomes as a result of traditional pastoralist rangeland management processes being revitalized under Save the Children's CB/PNRM intervention

Result of Save the Children CB/PNRM intervention (in which research for this study took place)	Short-term benefit	Outcome
– 2,000,000 ha of rangeland under improved management, including wet season grazing areas – 4,365 ha of private enclosures dismantled – 16 settlements relocated – 10,396 ha of communal enclosures established/ upgraded	– Increased access to nutritious pasture for livestock during dry seasons leading to improvements in livestock body condition and reduced livestock mortality	– Increase in livestock market price – Shift in livestock market value from wet season to wet and dry season – Two-year-old bull increase in price during dry season from 1,000–2,000 Ethiopian Birr (ETB) without access to communal grazing enclosures to 3,000–4,000 Birr with access under PNRM – One-year-old shoats and calves now hold market value – Perceived shift in livestock market access: traders coming to the community – Increase in number and more drought resilient livestock types owned per household (i.e., camels)
	– Increase in meat and milk production due to access to increased number of improved (nutritious pasture quality and size of pasture available) communal grazing areas for livestock in dry seasons	– Increased food security for children and households – Change from no dry season milk pre-intervention to 2–3 caps of milk per day per cow – Ability to sell excess dry season milk production in the local market
– 67 migration routes reopened – 55 salt lick routes reopened – Nine traditional water points rehabilitated – Seven shallow well water points rehabilitated – Three pond water points rehabilitated	– Better access to existing grazing and water sources due to reopening of roads/ migration routes – Salt licks reopened facilitating improved access to a key natural resource for livestock health	– Improved access to water sources for livestock during wet seasons after the rainy season has ended, although secure access still problematic leading to potential early migration to dry season grazing areas – Increase in access to mineral and salt lick sites resulting in improved livestock health especially during wet seasons – Farmers reducing enclosed land holding areas to perimeters of cultivatable

(*continued*)

Table 3 (continued)

Result of Save the Children CB/PNRM intervention (in which research for this study took place)	Short-term benefit	Outcome
		agricultural land rather than extended plots blocking road and migration route access and privatizing large areas of key rangeland resources that were previously "common" property
	– Reduced water collection time for women due to improved access to water sources (from a 3-am start and 6-pm finish to a 10-am start to 3-pm finish) and change in water management structures reducing manpower required to physically retrieve water (from eight to four people needed) – Reduced time searching for grass for livestock during dry seasons due to wet/dry season grazing divisions and new hay making skills fostering availability of grass in dry seasons	– Increased time for alternate household responsibilities, including attending decision-making meetings for women engaged in PNRM processes

This links to another result on the CB/PNRM Resilience Scale in Fig. 4 below: **building community cohesion through bottom-up participatory approaches leading to a shift in mindset from "individualism" to "communal" use of rangeland and natural resources and wider stakeholder solidity across the broader institutional landscape**. The bottom-up approach used at large in Save the Children's CB/PNRM intervention is also *transformative development* as it moves beyond conventional development planning and project processes that focus on "outcomes" rather than "process" as well. The "conducive environment to participate actively in managing resources properly" has facilitated a change in community mindset from individualism to communal use of rangeland resources (Deedha and Reera Customary Institution members). It has also enabled community and institutional cohesion with increased accessibility to government institutions identified as important for livelihood support at community level. "Before all stakeholders worked separately. PNRM is best as it brings people together" (Liben District Land and Environmental Protection Office). Working together through collaborative practice is also *transformative development*. This is because it breaks the boundaries of conventional practice that often isolate different stakeholders and their needs from each other.

10. **Community openness to test indigenous knowledge systems with external relevant information bases**

    By merging traditional knowledge with external expert information to generate improved community outcomes, community stakeholders are open to move beyond the boundaries of their own traditional knowledge base and adjust systems with relevant information to meet community needs in light of changing circumstances – a key component of adaptive capacity. "Save the Children told us to enclose an area but we knew this before. What is different now is that we use new skills in this area such as piling of hay [and prescribed fire] so the area of land is more productive for us" (Reera Customary Institution members). Also, project participants are innovating through altering practices shared on a small scale – another key component of adaptive capacity. These results suggest a move beyond conventional approaches to those that are more *transformative*, and closer to *ACV/DRR* than development, because the mechanisms in place facilitate improved practice in the current context of climate variability.

11. **Responding to climate vulnerable poor needs through inclusivity respectful of pastoralist traditions, including benefit sharing mechanisms resulting in reduced livelihood vulnerability and improved coping capacity**

    In a climate change context, ensuring the needs of the poorest and most marginalized are identified and addressed is important, as climate impacts will potentially increase respondent vulnerability levels. Save the Children has targeted most vulnerable needs through an inclusive community approach that is culturally appropriate for pastoralist groups. This evidence is viewed as *transformative development* on the CB/PNRM Resilience Scale. Similarly, this evidence is transformative as empowerment of the climate vulnerable poor has been increased through benefit sharing mechanisms that adjust previous structures that did little to support the poorest and most marginalized households engaged in NRM (Napier and Desta 2011). For example, shifting allocation from livestock grazing to hay making in upgraded community enclosures results in less well-off households incurring more benefits than better off households due to increased numbers of poorer households engaged in improved hay making practices. Likewise, assigning less well-off households without livestock designated areas to practice improved irrigated farming supports reduced livelihood vulnerability and improved coping capacity.

The non-Save the Children CB/PNRM Intervention Site

The overriding comparison between study sites is that Save the Children's results primarily fall between *transformative development* and *transformative ACV/DRR* on the CB/PNRM Resilience Scale. Results from the non-Save the Children site fall largely under *conventional development*. In addition to the results presented in Table 1 above, discussion and analysis highlighting key differences is presented here.

Community stakeholders at the non-Save the Children study site were operating on an existing pastoralist livelihood system paradigm that was no longer producing effective results in light of local changing circumstances with respondents unable to adapt with change. One component contributing towards this outcome is as follows: **lack of access to and integration of short-term weather and longer-term climate information in planning and decision-making processes at community level**. This result is placed under *conventional development* on the CB/PNRM Resilience Scale in Fig. 5 below. New climate change and adaptation science that integrates local knowledge with relevant and meaningful scientific climate information is required for effective adaptation.

Another key component for why coping strategies undertaken were not forming the basis of successful long-term adaptive strategies needed to address current and future climate change risk is that non-Save the Children respondents lacked understanding, ability, innovation, and access to relevant information regarding how to adapt their livelihood and rangeland management strategies to address perceived climate variability changes. "We're still keeping livestock in the old ways when there was grass and water" (male non-Save the Children intervention site members). In addition, community stakeholders view their surrounding ecosystem not as a holistic functioning system for resilience-building but as the provider of key natural resources that their livestock depend on. The results of this approach are shown in Table 4 below. The outcome of **implementation of existing livelihood and land use strategies despite perceived climate variability changes to local context leading to reduced livelihood outcomes**, **land productivity, and biodiversity**, and its associated results highlighted in Table 4 below are placed under *conventional development* on the CB/PNRM Resilience Scale.

Likewise, **lack of community access to new and improved information and capacity bases required for alternate livelihood strategies**, **improved rangeland management practices, and adaptation** that contributes towards the results in Table 4 above renders its position under *conventional development* on the CB/PNRM Resilience Scale in Fig. 5. Non-Save the Children community stakeholders do have access to local government institutions, but government capacity for meaningful support through desired learning-by-doing approaches is lacking. "We want practical training so we can learn properly" (male non-Save the Children intervention site members). Nevertheless, community openness to improve traditional NRM knowledge bases through expert information integration and more beneficial learning mechanisms to support adaptation moves towards *transformative development*.

One important difference between study sites relates to gender. Women at the non-Save the Children site were not empowered. They were unable to raise their voices and participate in community decision-making and therefore unable to realize their potential role as strategic agents of community adaptation processes. Consequently, this result **of male-orientated decision-making processes undertaken**

Table 4 Results showing lack of rangeland resilience and its consequences for non-Save the Children community stakeholders

Absence of new/improved action	Outcome of absence of new/improved action
– Wet/dry season mobility operational but ineffective in providing access to sufficient pasture and water access in changing context circumstances – Increasing lack of access to water in dry season for livestock and households – Lack of access to salt lick resources – Lack of conservation of degraded land (e.g., through soil/water conservation techniques; planting grasses) – Lack of diversified livelihoods (e.g., hay making) – Lack of improved crop cultivation techniques	– Pasture in dry season enclosures being consumed quickly due to increased number of livestock rendering insufficient pasture for length of dry grazing seasons – Reduction in livestock body condition and livestock price (6,000–8,000 ETB to 300–1,000 ETB) – Reduction in milk availability for household consumption – Livestock able to migrate when grass is available – Salt licks not easily accessible as located in far distances – Teff/crop residue/straw/hay purchased from highland areas at high prices – Understanding of need to keep hay for crisis periods – Donkeys used for water collection from far distances to support access to water, especially for weaker calves – Women undertake a 14-h journey to collect and carry 20 l of water from nearest town areas – Trees and plants drying out and dying – Reduction in wildlife – Reduction in land productivity and ecosystem services – Shift from multi- to mono-crop cultivation

with lack of female inclusiveness and empowerment is placed under *conventional development* on the CB/PNRM Resilience Scale.

Evidence does however highlight signs of male community stakeholders potentially shifting mindsets on women's role in NRM processes. "Our previous thinking was that women are not fit for our work as it requires strength. But now we realize that women would be beneficial. A kallo protected by women in another area is in much better condition that ours" (Male non-Save the Children intervention site members). This **new understanding and insight into the beneficial role of women in NRM processes** is considered *transformative development* on the CB/PNRM Resilience Scale.

Key Recommendations

This study has shown the value of CB/PNRM as an adaptation strategy in the context of the Ethiopian dryland pastoralist communities. While climate change was not a specific focus of the Save the Children CB/PNRM intervention design, many of the activities implemented made important contributions to building local adaptive capacity. Comparisons with the non-Save the Children site, where most activities were closer to *conventional development* than *transformative development* or *transformative ACV/DRR*, reinforced these observations. This suggests that the potential role that development actors, such as Save the Children, can play in the context of adapting to climate change merits further attention among governments and policymakers. Likewise the role that sustainable natural resource management can play as an adaptation strategy, particularly for poor and vulnerable groups such as the Borana pastoralists, merits further attention when compared to alternative infrastructure or technological adaptation solutions. Chishakwe et al. (2012) and Munroe et al. (2011) argue for the need for newer fields of study such as community-based adaptation to learn from older disciplines such as CB/PNRM, and this study reinforces this recommendation.

Conclusions

The aim of this study has been to assess the effectiveness and contribution of CB/PNRM in building resilience to current and potential future climate change impacts for pastoralists and agropastoralists in Ethiopia. To achieve this, the processes used and the results obtained by Save the Children's upgraded CB/PNRM intervention compared to CB/PNRM with no external support has been analyzed in light of local climate and non-climate risk factors.

Based on the long-term presence and existing rapport between Save the Children and project stakeholders in the selected CB/PNRM intervention sites, together with a thorough understanding of the pastoralist systems in play and a more conducive institutional environment for change supported by recent government learning, Save the Children's CB/PNRM work has produced strong results.

Results show that much has been done towards moving from conventional approaches to development (and adaptation to climate variability including disaster risk reduction) to *transformative development* approaches that empower local people and support bottom-up, participatory, flexible decision-making and planning processes within a strong institutional context. This includes incorporating local and scientific climate knowledge focused on climate variability trends into planning. However, locally meaningful scientific climate change information still needs to be merged with local knowledge bases so it can be mainstreamed into community and institutional decision-making processes across scales to support adaptation to uncertain future climate change impacts.

Much has also been done towards moving from conventional development approaches towards those that support adaptation to climate variability including disaster risk reduction (ACV/DRR). Although project activities were not initiated with improving climate change resilience as a key goal, evidence shows that many of the development-oriented processes implemented have made important contributions towards this outcome. In an adaptation to climate change context, this is significant as it means that Save the Children has largely moved beyond conventional development and ACV/DRR methods that typically lack the ability to foster sustainable resilience-building in an uncertain and changing environment.

Save the Children's CB/PNRM intervention has achieved this through the following means:

- Moving from a short-term projectized approach to planning towards the facilitation of longer-term change processes
- Application of an integrated project approach that has engaged local institutions and improved partnerships between government and community members, including joint action between government and traditional customary institutions
- Strengthening local institutional processes fostering an enabling environment for adaptation by addressing basic needs through improved access to key assets and resources and new and improved livelihood strategies leading to enhanced local adaptive action
- Meaningfully engaging respondents in PNRM community-driven planning and decision-making processes, especially women, through strong participatory and collaborative methods increasing individual and community empowerment plus bottom-up accountability, especially for those most marginalized community members
- Project participants shifting their mindset from viewing their ecosystem as a provider of natural resources to a more holistic understanding of environmental system linkages
- Targeted community members possessing improved development capacity to cope with and respond and adapt to current context situations including climate variability, with subsequent decreases in poverty levels, and increases in food security and livelihood outcomes

As a result, targeted community stakeholders feel they possess the knowledge and capacity to cope with and adapt to increasing drought scenarios. Joint community and local government action plans and agreements by local government authorities facilitating improved access to appropriate wet and dry season grazing areas, combined with new livelihood and rangeland management techniques, have led to an increase in adaptive capacity which evidence suggests is likely to increase respondent resilience in light of, or in spite of, climate risk. This means that Save the Children's CB/PNRM intervention has helped strengthen the local institutions and strategies required by respondents to ensure higher productivity levels and thus greater accumulation of assets, improved diet and income, and the increased capacity to protect these gains, in a context of unpredictable distribution of resources and periodic extreme events.

In stark comparison, a site visited without Save the Children CB/PNRM interventions to provide comparative results of project and adaptation outcomes showed that existing pastoralist livelihood systems were no longer producing effective results in light of local changing circumstances with respondents unable to adapt with change. Evidence showed that respondents' were not bouncing back to previous productivity levels before changing drought conditions, with productivity levels appearing to be in slow decline over time. Coping strategies undertaken were not forming the basis of successful long-term adaptive strategies needed to address current and future climate change risk.

This reflects the results of previous research in the Borana Zone, which found that while communities were in agreement "that diversification of financial resources and income generating activities is key to adapting to changing conditions, whether this means engaging in petty trade, sale of firewood and charcoal, construction and renting of houses, honey and alcohol sale, business creation and management, or learning to save money using financial institutions," limited access to information and "limited education, skills and access to financial services and markets required to diversify their livelihoods" limited pastoralists' ability to adapt (Riché et al. 2009). The research found that a lack of appropriate knowledge and experience meant that communities suggested different and sometimes contradictory adaptation strategies in light of expected changes: "For example, pure pastoralists suggested that agro-pastoralism would be a better livelihood strategy to deal with climate change, while agro-pastoralists would like to drop out of their farming activities due to increasing crop failure" (Riché et al. 2009).

The results of Save the Children's CB/PNRM intervention have contributed towards reducing livelihood vulnerability and increasing resilience for its project participants by leaving behind a legacy of empowered people more able to cope with and adapt to current climate variability risk through strong development-based outcomes of "good" development and improved institutional governance.

However, more progress needs to be made to further strengthen respondents' ability to adapt to current climate variability risk and importantly to future climate change impacts. Undertaking *transformative development* and *transformative ACV/DRR* approaches is necessary but is only part of the process towards the long-term goal of *transformed climate change resilience*, whereby resilience is built at scale, resulting in the successful longer-term adaptation of the climate vulnerable poor to climate change impacts through sustainable adaptation strategies (Ayers and Faulkner 2012; Faulkner 2012b). Among others, improvements in generating and integrating new knowledge about adaptation and future climate change across scales from community to local institutional levels is required.

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Assessing the Impact of Rainwater Harvesting Technology as Adaptation Strategy for Rural Communities in Makueni County, Kenya

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Abstract

Rainfall scarcity is a constraint to productivity in arid and semiarid regions of Kenya. This chapter identifies the common rainwater harvesting technologies used in Makueni County, a semiarid region, both for domestic and agriculture production as a way of adapting to climate change and variability. Household interviews were held for 134 households from five villages in addition to collection of secondary data from the area. The results revealed that 30 % of farmers have water tanks in their home, 90 % are members of communal sand dams and ponds, while 70 % use road water harvesting to supplement rain-fed agriculture. The constraints for adoption included lack of labor and skills. Different coping strategies applied by small-scale farmers who practice rain-fed agricultural production in this region include soil moisture retention practices such as terracing and use of sand dams as well as storage of water for domestic use in tanks. This valuable information will provide best home-grown practices and reveal gaps on rainwater harvesting which can be implemented by extension officers and local stakeholders. The adoption of these important technologies can be a basis of curbing related problems under similar conditions.

Keywords

Adaptation strategy • Makueni County • Rainwater harvesting • Climate change and variability

Introduction

The Effect of Climate Change on Water Resources

Africa is characterized by a wide variety of climate systems ranging from humid equatorial systems through seasonally arid tropical to subtropical Mediterranean-type climates (Hulme 2001). These climates exhibit differing degrees of temporal variability, particularly with regard to rainfall amount and distribution. Climate change is often used to include the occurrence of medium-term changes in weather patterns, increased climate variability, and more frequent climatic extremes such as droughts and floods (IPCC 2001). It is usually associated with increasing frequency and intensity of droughts and water scarcity that aggravate food insecurity and poverty in rural communities.

The Fourth African Assessment Report on climate change released by the Intergovernmental Panel on Climate Change (IPCC) highlights major issues related to potential impacts due to climate change (IPCC 2007). It indicates that Africa is one of the most vulnerable continents to climate change and climatic variability. This is a result of the interaction of multiple stresses including land degradation and desertification, declining runoff from water catchments, high dependence on subsistence agriculture, HIV/AIDS prevalence, inadequate government mechanisms, and rapid population growth occurring at various levels. Africa also has low adaptive capacity due to factors such as extreme poverty, frequent natural disasters such as droughts and floods, and rainfall-dependent agriculture (Boko et al. 2007). Due to this vulnerability, it is estimated that between 75 and 250 million people are likely to be exposed to increased water stress by 2020. The rain-fed agricultural yields could also be reduced by up to 50 % (Boko et al. 2007). These impacts will be aggravated by climate change unless strategies to address climate change-induced water stress are adopted.

In an attempt to overcome climate change and other challenges facing them, many African countries have crafted strategic plans detailing how they intend to deal with these global issues. For instance, Kenya has developed the Kenya Vision 2030 plan. One of the key factors of Kenya Vision 2030 is to transform Kenya into a newly industrializing middle-income country providing a high-quality life to all its citizens by the year 2030 (GoK 2007). This is also emphasized in the Kenya Economic Stimulus Program (ESP) objectives of investing in long-term solutions to the challenges of food security and economic opportunities in rural areas for employment creation (KNAMP 2010). The Millennium Development Goals (MDGs) 1 also aim at eliminating extreme poverty and hunger using sustainable methods by the year 2015. However, by the projections of the year 2008, it was apparent that no African country was likely to achieve all its goals by 2015 (Achim 2006). Despite the Kenyan new constitution promulgated in 2010 stating that "Every person has the right to clean and safe water in adequate quantities" (GoK 2010), an estimated 41 % of Kenya's population live without access to safe drinking water, relying on unprotected wells, springs, or informal water providers (UNICEF 2010). With regard to water availability, like many other countries, Kenya is below the international water scarcity threshold (1,000 m^3 per person per year) with only 935 m^3 available per person per year (FAO 2007), and population growth is forecasted to reduce this figure to 359 m^3 by 2020 (UN-Water 2006).

To curb water scarcity, programs such as the Integrated Water Resources Management (IWRM) project were established in 2002. This project promoted and coordinated development and management of water, land, and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP 2010). The project was done in Makueni County. Makueni County, located in Eastern Kenya, is hot and dry with erratic and unreliable rainfall. The people of Makueni rely on an inadequate, fragile, and uncertain resource base under constant threat of drought, resulting in food insecurity and undernutrition (Ismail and Immink 2003).

Introduction to Makueni County

Makueni County is one of the most food-insecure areas of the country with over 70 % of households classified as poor or very poor (WMS 1998). The farmers practice subsistence farming under rain-fed agriculture. It is for this reason that Makueni County was selected as a case study, and any results obtained in the county would be fairly representative of the other parts of the arid and semiarid regions. The county is unique because climate in this region falls under two climatic zones: arid and semiarid with most of the district being classified as arid. Researching in this county therefore offers a very good opportunity to see the difference in the coping strategies to climate change for the people in arid and semiarid regions. This is important because with the high rate of impacts of climate change, the semiarid regions may in the future be arid. The lessons learned in the arid regions may be used to prepare the people in the semiarid areas in Makueni County and other currently semiarid areas to cope with the expected and impending aridity in the near future.

Adaptation of Makueni Residents to Climate Change

Some of the adaptation measures to water stresses during droughts and high rainfall variability include adoption of supplemental irrigation, rainwater harvesting, and storage (Nkomo et al. 2006; Osman et al. 2005). Measures used specifically for agriculture in Makueni include planting of drought-resistant crop varieties, use of certified seed as opposed to planting grain from previous harvests, early-maturing crops, promotion of small livestock improvement, establishment of group seed bank, promotion of credit access and food storage, and improvement of water exploitation methods such as shallow wells, roof catchment, and sand dams among other water harvesting technologies (Speranza 2008). Crop and animal diversification, income diversification, and feeding animals on preserved hay and mineral salts are also some of the strategies for adapting to climate change (Mutambara et al. 2012). Adaptation to climate change and its variability necessitates the adjustment of a system to moderate the impacts of climate change through taking advantage of new opportunities and coping with the resulting consequences (IPCC 2001).

The Need for Rainwater Harvesting in Makueni

Makueni has only one perennial river with numerous streams. Therefore, alternative ways of addressing the drawbacks and water scarcity in this region are through maximizing the use of rainwater through rainwater harvesting (RWH) as well as improving soil and water management. Rainwater harvesting is mainly the collection of runoff for its productive use. It can also be defined as a method for inducing, collecting, storing, and conserving local surface runoff for agriculture in arid and semiarid regions (Boers and Ben-Asher 1982). It is one adaptation measure that does not require large capital investment and is essentially a management approach, to provide water resources at the community level and ensure livelihoods are maintained (IRIN 2006). The use of rainwater harvesting leads to a reduction in water costs, ease of water acquisition, and control of floods and soil erosion (Reiz et al. 1988; Zhao 1996; Li et al. 1999; Wang et al. 2005). RWH is also simple to operate and manage and therefore ideal to rural communities such as those in ASAL regions (Li et al. 1999).

Soil and water management is a must for agricultural production in ASAL regions. The harvested water seeps into the ground through embankments and impediments such as bunds and terraces, where it is stored in mulch in the case of in situ micro-catchments for prolonged use by plants. Encouraging infiltration of rainwater also raises the water table and makes water readily available for plants or in shallow wells.

While RWH systems can improve agricultural production and reduce drought in semiarid environments, their performance and effectiveness is limited by high water losses, inadequate storage capacity, and poor water management (Ngigi 2009). Thus, improving the access of poor people to water has the potential to make a major contribution toward poverty eradication through improved agricultural production as well as enhanced food security.

RWH promotes gender equality and empowers women by availing water close to their homes and limiting the distance they have to travel to fetch it as well as increasing food production and nutrition (Lehmann 2010). It has however been shown that water-related enterprises such as agricultural development projects have a far greater success rate when women are involved than when they are excluded (Achim 2006). According to the World Water Development Report, many girls are prevented from attending school because they are in charge of collecting domestic water (Achim 2006). Thus, rainwater harvesting as a decentralized water supply system eliminates women's burden of collecting domestic water. Rainwater harvested from rooftops supplies relatively clean water, which when filtered, treated, and stored, provides a safe and clean source of drinking water. Thus, women and the girl child use the time saved from collecting water on education and other income-generating activities.

Adoption of RWH ensures environmental sustainability because communities are able to engage in more crop production including tree planting activities that lead to increase in the proportion of land area covered by forest, which help to maintain biodiversity. According to Mati (2006), rainwater harvested from rooftops coupled with storage and use of drip irrigation kits has relatively increased in East Africa.

Description of RWH Systems Commonly Used for Domestic and Agricultural Use

Inadequate access and quality water for both domestic and agricultural use was identified as the main challenge in the Makueni District Vision and Strategy 2005–2015 (PWC 2005). Due to this there exist various water harvesting technologies in the county.

Water Tanks

Water tanks mostly harvest water from rooftops. Tanks are popular for saving water, are easy to use, and are available in styles to suit most homes. Harvesting water with tanks involves three primary components: catchment, conveyance, and a collection device. Rainwater drains down the slanted rooftop to the conveyance instruments, or gutters, at the base of the roof. The gutters transport the water from the rooftop to the collection device. The advantages of water tanks include the fact that it is a simple technology which provides free soft water that lathers easily, saving on soap and detergent. It also provides extra water available for kitchen gardening and one can get any size of the tank. However, the cost of tanks is high for most smallholder farmers with the rainwater tanks needing careful management to prevent mosquitos from breeding in them (Kheradi 2011). Figures 1 and 2 show different types of tanks used by the community.

Sand Dams

Sand dams are small impermeable barriers constructed across the bed of seasonal streams. Sandy riverbeds are required for a sand dam to work properly. Sand dams vary in size according to the riverbed. It is a very simple technology and inexpensive since construction materials are locally available. In most cases, the labor

Fig. 1 Water tank 1 for domestic use

Fig. 2 Water tank 2 for domestic use

required to build the barrier comes from the local community. Another benefit of having the water stored underground is that it is less vulnerable to contamination and disease-carrying insects, such as mosquitoes, since there is no medium for laying their eggs. Sand dams are very low in construction costs. All that is needed to build them is wood to form the barrier, reinforcing material, and concrete or masonry as shown in Fig. 3. Being a simple structure, there are minimal to zero maintenance costs associated with sand dams (PA 2008; RHIN 2007; Stern 2011).

Zai Pits and Negarims

Zai pits were traditionally invented by farmers in Burkina Faso (NDMA 2011). In Kenya, they are referred to as planting pits and are boxlike structure in cross section as shown in Fig. 4. They are constructed by excavating the soil and returning the rich top soil with organic mulch, while the subsoil acts as an embankment behind the pit. A tree crop or several plants like maize and beans are then planted in the pit.

Fig. 3 Sand dam at Makueni County

Fig. 4 Zai pits at Makueni County

The mulch soaks up the water and stores it throughout the dry season. Similarly, negarims act in the same way except that they are mostly used for tree crops and involve a formation of square embankments. Some of the advantages of using Zai pits and negarims are the fact that they can be reused for up to four crop seasons or two seasons without the need to add more manure. In addition they increase crop yield and enable better crop survival in drought time, promote ease of weed control, conserve water through reduction of soil erosion, as well as improve soil fertility and environmental conservation (NDMA 2011). However, Zai pits require heavy labor for preparation and may not work well in waterlogging soil.

Rock Catchment

Rock catchments are systems which mainly use natural rock surfaces to divert rainwater to a central collection area (Fig. 5). The collected rainwater passes through sand and gravel before storage in a water reservoir or tank. The sand and gravel act to filter and make the water clean.

Bunds

Bunds are large earth banks on the contour that trap runoff (Fig. 6). Bunds vary in shape. They are usually built to prevent runoff and conserve water. Bunds are simple to build, improve productivity, and keep water in the soil. Despite this, bunds use a lot of land, may create temporary logging, and may interfere with farm operations if the bunds are too close to each other. However, they are labor intensive (Yongon 2008).

Water Pans and Ponds

Water pans and ponds are excavations or embankments that are constructed on the path of natural rainwater catchments and used as water reservoirs (Fig. 7). To create a leakproof water reservoir, it is necessary to use an impervious layer of soil or line the reservoir with plastic material to form the plastic-lined dam. A recent

Fig. 5 Rock catchment

Fig. 6 Trapezoidal bunds

Fig. 7 Water pans

innovation in Kenya used by farmers that lack a large catchment area is the diversion and collection of rainwater from road drainage, a method commonly known as road runoff harvesting. This method has become so popular along some roads, some farmers have conflicts as farmers up the road divert all the water

Table 1 Classification of uses of RWH technologies

Domestic use	Agricultural use	Domestic and agriculture
Water tanks	Water pan	Water pans
Water pans	Road harvesting	Farm ponds
Farm ponds	Zai techniques	Sand dams
Sand dams	Bunds	

leaving little or no water for farmers down the road (Ngigi 2009). This study identified the types of rainwater harvesting method for domestic and agricultural use and the impact to smallholder farmers in Makueni County (Table 1).

Methodology

Description of the Study Area

The study was conducted in Makueni County which is located in the southern part of the Eastern Province of Kenya in East Africa. The elevation is 1125 m above sea level, latitude 1° 50′S and longitude 37° 14′E in the transitional zone between agroecological zones IV and V. Makueni County is characterized by extreme rainfall variability. The region receives mean annual rainfall of about 500–600 mm annually (Njiru 2012). The rainfall pattern is bimodal with two rainy seasons with two peaks in March/May (long rains) and October/December (short rains). The dry period occurs from June to October and from January to March. Precipitation is highly influenced by topography; the hill masses receive higher amounts of rainfall in the range of 1,200 mm, the medium zone receives up to 750 mm, and the very low-lying zone averaging 600 mm of rainfall per year, respectively.

Temperatures in Makueni County are high throughout the year which causes high evaporation. The area experiences temperature ranges of between 18 and 24 °C during the cold seasons and 24 and 33 °C in the hot seasons. The mean annual potential evaporation in the central and northwestern ranges between 1,800 and 2,000 mm, while in eastern and northeastern is from 2,200 to 2,400 mm (PWC 2005). However, the overall drainage pattern in the county is from west to east. Figure 8 shows a map of Makueni County.

Sampling Techniques and Data Analysis

A two-stage sampling technique was applied to select the households. In the first stage, 178 households were randomly interviewed from a list of 400 households. In the second stage, a total of 134 households from 178 households who were practicing at least two rainwater harvesting systems were considered for the analysis. Data analysis involved both the primary and secondary data. The analysis of quantitative data was done using MS Excel and presented as percentages in graphs. The study was conducted in June 2011.

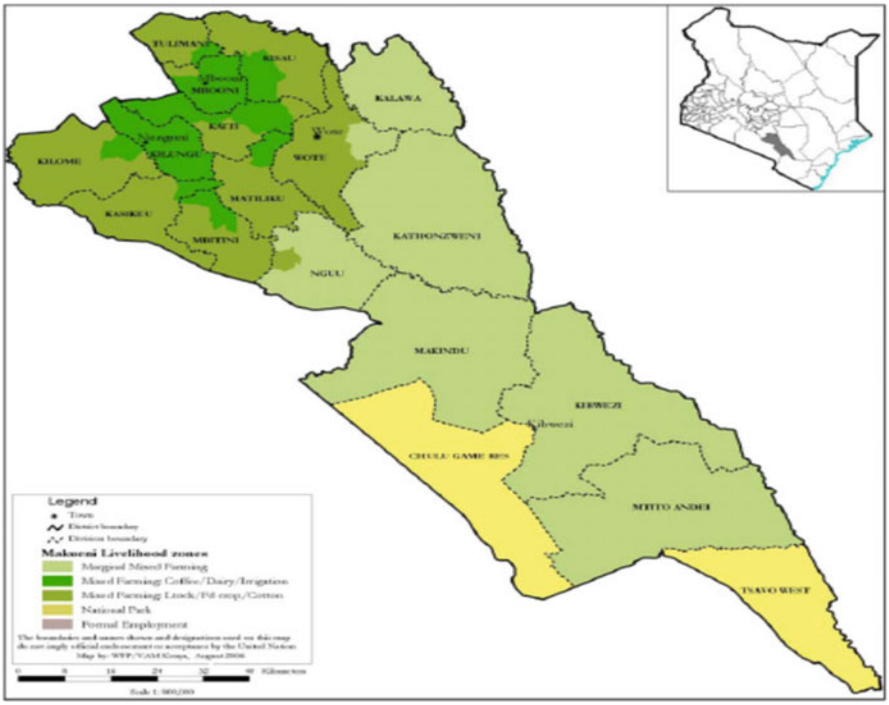


Fig. 8 Map of Makueni County (CRA 2012)

Results and Discussion

Summary of Results

Farmers were asked to point out the rainwater harvesting technologies they were using. Majority (95 %) were using terraces, with 90 % mentioning communal sand dams. Road harvesting (70 %) was also popular among the farmers. Water tanks were used by 30 % of households, and this may be due to the fact that only 48.1 % of the housing units in Eastern Kenya are roofed with iron sheet roofs, asbestos cement sheets, concrete, or clay tiles. Figure 9 indicates that on average, 51 % of the households were using water pans, farm ponds, and sand dams for multipurpose use, while 30 % used water from water tanks for domestic use especially for drinking.

The Adoption of Rainwater Harvesting Technologies

The rainfall data presented in Fig. 10 gives an interesting picture of rainfall in Makueni. Although most references talk of a bimodal rainfall pattern, it would seem that there is only one rainy season that starts around October and peaks in

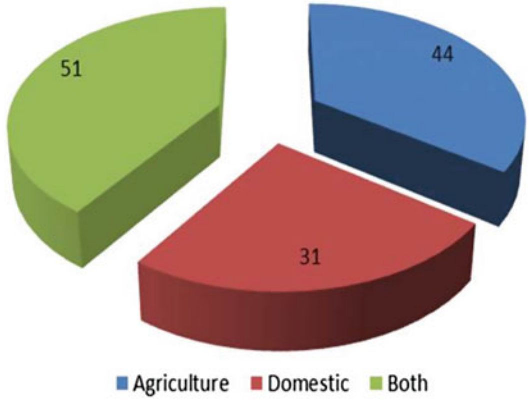
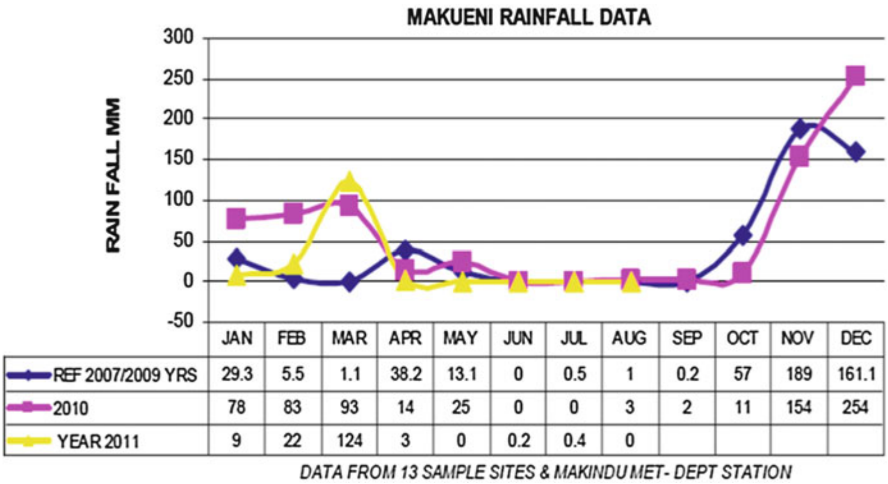


Fig. 9 Classification of rainwater harvesting technologies according to use



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
REF 2007/2009 YRS	29.3	5.5	1.1	38.2	13.1	0	0.5	1	0.2	57	189	161.1
2010	78	83	93	14	25	0	0	3	2	11	154	254
YEAR 2011	9	22	124	3	0	0.2	0.4	0				

Fig. 10 Rainfall (mm) in Makueni County (GoK 2011)

November or December. These rains continue through April, albeit in suppression save for a small blip in March or April. There is then a 6-month dry spell with almost no rain at all. This is the period where rainwater for domestic use becomes a critical factor. This is because of the need to have a storage structure large enough to store water to last households over the 6-month dry spell.

It may therefore be concluded that the construction of water tanks may not be as viable as construction of water pans. This is because one would require a relatively large (and costly) tank to cater for the household for half a year. On the other hand, sand dam stores large volumes of water for long distances behind the barrier. Since the water is under the sand, it is safe from the high evaporation due to the high temperatures in the dry spell. In this study, 90 % were harvesting water from sand

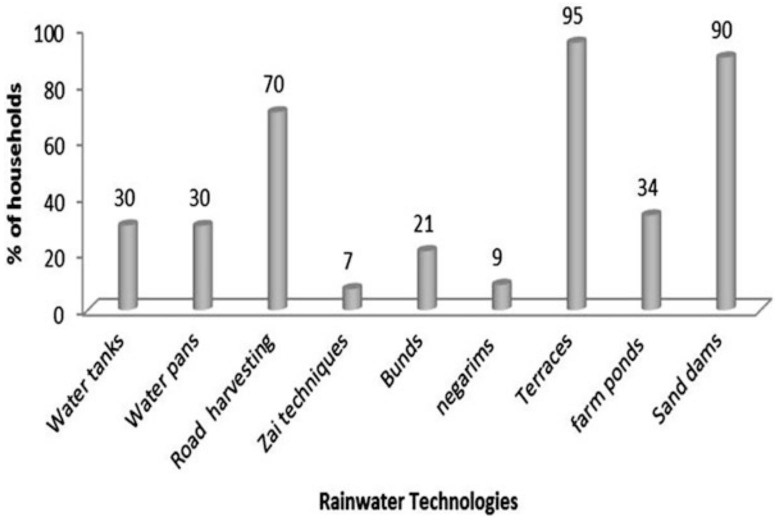


Fig. 11 Rainwater harvesting technologies

dams as to 30 % from water tanks. However, there was no difference in terms of the percentage of households harvesting water from water tanks and water pans (Fig. 11). Of the farmers, 95 % use terraces for soil and water conservation while 70 % harvest water from roads. This shows that almost half the farmers understand the importance of in situ rainwater harvesting technologies for improvement of yields. The unpopular technologies included Zai pits (7 %) and negarims (9 %). The reason for the low adoption was that these are relatively recent technologies on which the farmers have not been fully sensitized. However, Zai pits have been shown to increase yields in Kitui and Mwingi (Tran 2011; Njue 2012). For this reason, sensitization should be done to farmers by extension workers and other stakeholders particularly for the improvement to fruit trees like mangoes.

The case of Zai pits and negarims is in sharp contrast to terracing which has been adopted by 95 % of the residents. There was aggressive promotion of terracing in the area by the Ministry of Agriculture since the 1960s, and the wide adoption of terracing shows that farmers understand the need for soil and moisture conservation. All the in situ RWH technologies such as bunds, negarims, Zai pits, and terracing are labor intensive. But given the enthusiastic adoption of terracing, it seems that the farmers are not discouraged by the labor intensity of the technology.

The results of this study were different from the CSTI (2009) whereby the most common sources of water in Makueni for domestic use during the dry season were rivers/streams (72 %), followed by wells (28 %) while boreholes and dams had 2.7 %. However, during the wet season the sources of water change with 46.7 % using rainwater for domestic use. The use of shallow wells also increases from 6 % during the dry season to 16 % during the rainy season. This points to the fact that even though the residents are increasingly adopting rainwater harvesting, the volume of water stored is low, and this is probably the reason why they resort to stream water as soon as the dry season sets in.

Motivation for Adoption of Rainwater Harvesting Technologies

According to Makabila (2013), the rainwater flowing on the seasonal rivers of Makueni County gets harvested in close to 100 sand dams. The water harvested is later used for domestic and agricultural use when the dry spell sets in. Between 2007 and 2008, Welthungerhilfe (WHH), a German relief organization, constructed five rock catchments in the Makueni District in Kenya's Eastern Province, providing safe drinking water to more than 19,000 people. However, this did not feature among the farmers interviewed. This may be because the project was implemented in a single village or it had not been adopted largely by most inhabitants as to spread to all farmers.

Rainwater harvesting systems are mostly practiced in ASAL regions. These regions are characterized with intense runoff events which make water storage a necessary integral part of the system (Oweis et al. 1999). This helps in mitigating the effects of temporal shortages of rain for domestic and agricultural purposes (Oweis et al. 1999; TWDB 2006). With Makueni being a semiarid region, the main reason for harvesting the rainwater was due to low and unreliable rainfall with 96 % of households. The second motivation was presence of seasonal rivers with 81 % (Fig. 12). The presence of seasonal rivers provided a conducive environment for construction of sand dams. Promotion and creation of awareness from Nongovernmental Organizations (NGO) besides subsidizing of the materials to the farmers also made 65 % of the household harvest water from the rainfall as shown in Fig. 12.

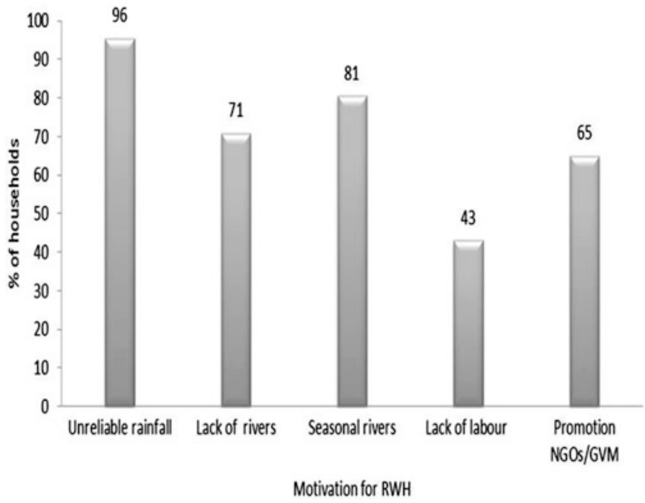


Fig. 12 Motivation for harvesting rainwater

Water availability saves energy, time, labor, and money, since water does not have to be carried to households from distant sources. While the harvested water leads to more reliable and greater yields, the members of the households can use their saved time to do other work, therefore generating more income as an output of the saved time. On the other hand, RWH at schools improves hygiene and nutrition, and pupils can spend more time learning, as they do not need to carry water to the school (Lehmann et al. 2010). Rainwater harvesting has also been found to increase the number of children attending school as well as decrease the walking distance to fetching water (Hauser 2012).

Since women are usually in charge of the household water supply (Lehmann et al. 2010), adoption of RWH empowers women because it gives them the possibility to get paid work where the presence of local employment is allowed. Also, RWH provides them with more time at their disposal, which can be utilized in other daily chores. Thus, their status as a decision-maker in the household increases. Most importantly, properly stored rainwater provides households with safe and hygienic water which reduces the risk of infection and child mortality and helps combat other severe diseases. It was estimated that poor water quality is responsible for the deaths of 1.8 million people every year worldwide (WHO 2004). RWH ensures environmental sustainability and can provide access to safe drinking water without threatening natural water sources.

Adoption of Rainwater for Domestic and Agricultural Use

The success of rainwater harvesting in arid and semiarid lands (ASALs) depends on the high demand of clean water supplies given that in Kenya, more than 67 % of rural households still have no access to clean and safe drinking water (Wanyonyi 1998). One of the main reasons the farmers were harvesting water was to increase yield (96 %) and get water for domestic use (96 %). Other reasons were to preserve water for use during the dry season (66 %) which is connected to increased yields, prevention of soil erosion (39 %), as well as irrigation (29 %) (Fig. 13). The availability of this water increases crop production because of the continuity in supply of this water to the farms in the form of drip irrigation or kitchen gardening. Most of the collected rainwater is used for irrigation, aquifer recharge, and storm water abatement (WHO 2006).

Factors Limiting the Uptake of Water Harvesting Technologies

Some of the identified constraints for implementing water-related projects in Kenya are financial constraints as well as lack of skills (Kinyua 2010). This is because rainwater harvesting technology can either be a complex or a simple technology to implement. However, for the people in Makueni, the major constraint was lack of labor with 69 % citing it (Fig. 14). From the study it was also found that the more compelling reason for the adoption of terracing is the recognition of its role in soil

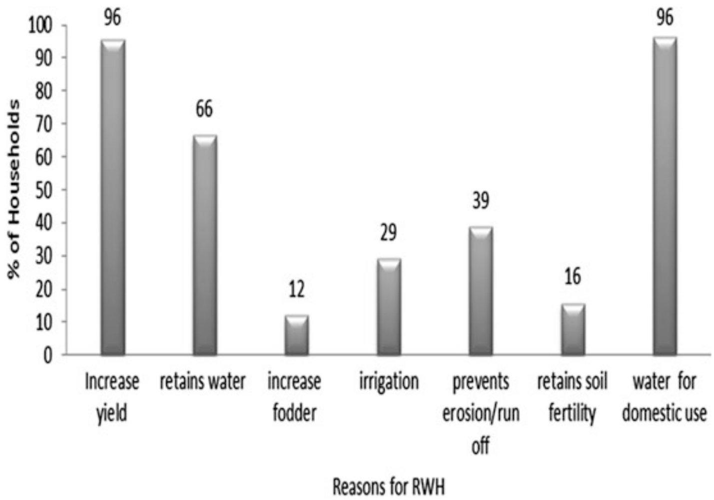


Fig. 13 Reasons for rainwater harvesting

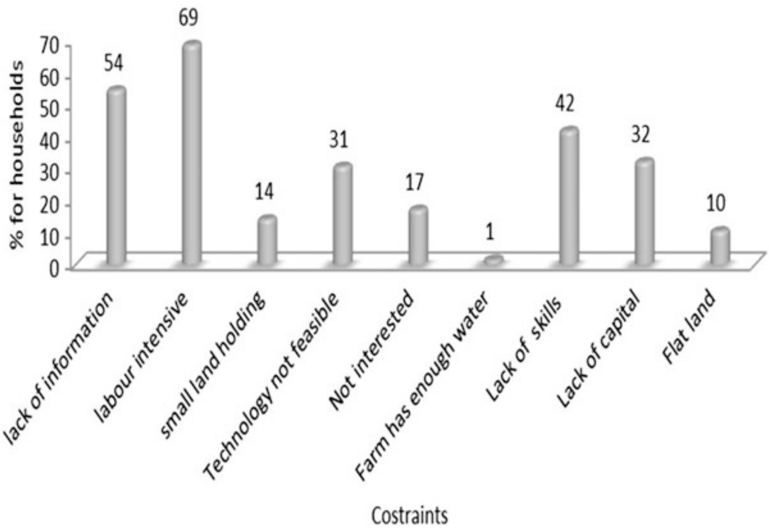


Fig. 14 Constraints of implementing rainwater harvesting

and water conservation arising from active promotion by extension officers over the years. To encourage increased adoption of terracing, perhaps the government can invest in community earth movers for hire or train the farmers in the use of animal draft technology for terracing and scooping dams.

The second constraint was lack of information about some of the technologies. This was evident in the low adoption of technologies such as negarims, bunds, and

Zai pits. Lack of capital did not feature as a main problem with 32 % of the farmers citing it. Only 1 % indicated that their farms had enough water (Fig. 14). RWH technology in Kenya is mostly implemented by self-help groups or communities that are not registered as required by the Water Act 2002. It has to be assumed that the Water Act 2002 does not encourage people to invest in RWH when there is no other option but to act outside a legal framework. Many organizations operating in community self-help water systems are not formally registered by the Ministry of Water.

Conclusion and Recommendations

It may be concluded that sand dams are an important source of domestic water with over 90 % of the population using it, while terracing is the preferred method of soil and water conservation. There is need to sensitize farmers on new technologies such as the use of negarims, Zai pits, and trapezoidal bunds since these are beneficial technologies that have not been adopted.

The high rate of adoption of terraces indicates that farmers are aware of the need to conserve soil and water, and even the labor intensity of the technology may not hinder them from practicing conservation measures that may help them to boost production of crops. However, investment in machinery for hire may encourage faster adoption.

Rainwater use seems to be confined to the wet season, with the residents using the streams and wells during the dry season. It may therefore be concluded that there is a problem of water storage that would otherwise extend the water availability through the dry season. It is therefore necessary to invest in water storage structures to ensure water availability all year round. Alternatively, groundwater recharge may be encouraged so as to raise the water table and ensure water availability close to the surface for enhanced crop production. Since the dry spell is long, the only viable technology for storage of water for domestic use is sand dams and more investment in this technology should be encouraged.

Rainwater harvesting forms the basis of solving water shortage problems in the ASALs. The government should fund such projects through the concerned Ministries of Water Resources Management and Development and provide reasonable percentages in the annual budget. Nonetheless, NGOs and Community-Based Organizations at national and local levels should be encouraged and allowed to play a role in putting rainwater harvesting in the limelight. Though this has been seen through the Southern and Eastern Africa Rainwater Network (SearNet) established with the assistance of the International Rainwater Catchment Systems Association and the support of the Regional Land Management Unit of UNEP (2009), more outreach programs should be put in place to expand the knowledge of water harvesting. Related workshops should also be used to expand this knowledge. The research recommends that at the local level, the government should fund water harvesting projects and provide farmers with harvesting materials such as gutters, roofing materials, concrete, and water tanks. An adaptation of the Kenya Water Act (2002) is necessary, in order to clarify the conditions under which various RWH structures can be implemented.

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Changes of South Baltic Region Climate: Agroecological Challenges and Responses

Galina M. Barinova, Evgeny Krasnov, and Dara V. Gaeva

Contents

Abstract

In this chapter, the regional dynamics of climate change and the subsequent agricultural challenges and responses are discussed by referring to the Kaliningrad region of the Baltic coast and some neighboring areas. The impacts of temperature and fluctuations in precipitation are discussed in relation to grain-crop harvesting and yields and other green crop productions. Furthermore, we observe the connection between pests and diseases and climate change, which affects livestock breeding, arable farming, and human living conditions. Some forms of adaptation to climate-related events (flooding, soil erosion, selection of appropriate crops) are also presented. In the past, during the Soviet era, new uncertainties and consequently

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deplorable ecological changes for the investigation area were caused by excessive use of pesticides, deforestation, and expansion of monoculture. Mathematical modeling and system approaches are thus becoming important tools for the creation of forecasting procedures and solution strategies and measures for feasible future development of agriculture. Special attention is given to a decreasing number of pollinators (domestic and wild). Finally, new forms of agricultural management (landscape planning, balanced and environmentally friendly agriculture practices) are stressed.

Keywords
Regional climate aspects • ecosystem impacts • strategies of adaptation

Methodology and Methods

The selection of materials for this study is based on annual and monthly averages of surface air temperature and precipitation at meteorological stations in the southern Baltic region from 1949 to 2011. A set of statistics referring to the period of time from 1960 to 2011 was collated relating to the agrarian structure in the Kaliningrad region (Russia) and the dynamics of crop yields and, more particularly, the total yield of grain and honey production from 1990 to 2011. Anomalies in average values of air temperature and precipitation were measured and recognized as deviations from the reference value recommended by the World Meteorological Organization for the period between 1961 and 1990. In order to analyze the variability of extreme air temperatures, minimum and maximum temperatures were each selected for every month in the period from 1949 to 2011.

These data serve to determine the ratio between climatic aridity and humidity and, therefore, in concrete terms, the index of aridity (understood here as the ratio between air temperature and precipitation values). The analysis reveals a significant interannual variability. The calculation of the atmospheric aridity index (S) (Frolov and Strashnaja 2011), using the values of temperature and precipitation for a certain period of time, reveals an increase in air temperature and a destabilization of hydrothermal conditions for the period 1949 to 2011:

$$S = \frac{\Delta T}{\sigma T} + \frac{\Delta P}{\sigma P}$$

ΔT, ΔP = air temperature and precipitation deviations from monthly mean values, respectively.

σT, σP = air temperature and precipitation from mean monthly values, respectively.

The atmospheric aridity index (S) is evaluated using the following scale:

– "Norm" = $1 \leq S \leq 1$.
– "Humid" = $S \geq -1$.
– "Arid" = $S \geq 1$.

History

This chapter focuses on the analysis of regional climate changes based on published studies, but also from different sources of information such as ancient chronicles, traditional knowledge and folklore, and natural scientific items such as the speed of lake sedimentation, analysis of annual rings, and measurements of land near-surface air temperature.

Three climate periods can be distinguished over the last thousand one hundred years:

(a) The warming during the first period, the Medieval Warm Period (from the end of the ninth to the beginning of the twelfth century), which began in the Baltic Sea area, resulted in shifts of vegetation zones and changes in vegetation. Thus, grapes were cultivated in northern Germany and even in Latvia. The increase in temperature during the early middle ages led to a corresponding increase in the numbers and concentration of different sections of the ancient population.
(b) The second main period (from the thirteenth to the eighteenth century), known as the "Little Ice Age," followed, during which the sea level lowered considerably, with extremely cold winters occurring over the ensuing centuries and the Baltic Sea being completely frozen. People could move over the ice-bound sea from Sweden to Denmark and could cover even longer distances by sledge, conquering new frontiers in the true sense of the word by traveling hundreds of kilometers, for instance, from Latvia to Sweden.
(c) It was only at the end of the nineteenth century that a new warming of the climate started to introduce the current climate conditions we live under and which are still going on, leading to the rise of the average global temperature and earth warming.

Reliable climate observations concerning climatic historical temperature variations are accessible at numerous meteorological stations that have existed for some centuries and deserve to be mentioned, such as St. Petersburg (beginning observations in 1725), Vilnius (1777), Warsaw (1779), Riga (1796), Tallinn (1806), Konigsberg-Kaliningrad (1848), and Tartu (1876). Analysis of the long-term data allows some conclusions to be drawn about the variation of air temperatures in the last two centuries:

- The second half of the eighteenth and the beginning of the nineteenth centuries are characterized by distinctive oscillations and low values of annual air temperature.

For example, the average annual temperature in the period between 1781 and 1790 in St. Petersburg was 2.8 °C.

- The lowest average annual air temperature of 4.7 °C was registered in both Warsaw in 1829 and in Königsberg/Kaliningrad in 1871. The coldest annual temperature (1.2–1.3 °C) was measured in St. Petersburg in 1809 and 1810.
- A new warming of the climate began at the end of the nineteenth century, leading to an average annual temperature of 7.5 °C in Kaliningrad and 8.4 °C in Warsaw.

Climate Change Dynamics

In the Kaliningrad region there are three main types of climate that, on the whole, can be subdivided into ten types of microclimates (Barinova et al. 2012):

1. Marine type:
   (a) A long period without freeze (190–200 days), a large number of serene days (30–32 days), normal humidity (750 mm) with strong winds and possible fog
   (b) The longest period without freezing (over 200 days), high recurrence of winds, annual rainfall of 600–650 mm
2. Transitional type:
   (a) Sufficient amounts of heat, strong winds, high temperature differences, and microclimatic difference in soil moisture
   (b) The lowest amounts of heat or a short period without freezing (<150 days), annual precipitation of 800–850 mm, excess humidity, moderate winds, frequent fogs
   (c) Sufficient amounts of heat, short period without freezing, weak winds
   (d) Sufficient amounts of heat, short period without freezing, moderate winds, increase in cloudy days, thunderstorms, fogs
3. Continental type:
   (a) A substantial an annual total (2,200 °C), mostly short periods without freezing (155 days), moderate winds, sufficient moistening
   (b) The greatest amounts of annual heat (2,300 °C), sufficient humidity, weak winds with sufficient amounts of annual heat (2,200–2,250 °C), an annual amount of precipitation of 700 mm, moderate winds, some days with fog
   (c) Sufficient amounts of annual heat (2,200 °C) or a short period without freezing (150 days), moderate winds, significant differences in temperature, and microclimatic soil moisture

Warming, especially evident in the last decade, has become a tangible factor in the development of agricultural production. Over the last 60 years (1949–2010), there has been a marked positive trend in the Kaliningrad region that involved an increasing mean annual air temperature and annual precipitation (Fig. 1). While in the first 30 years of the observation period the average annual air temperature varied between 6.5 °C and 7.5 °C, it has been 8.0–9.0 °C for the last 30 years, with a

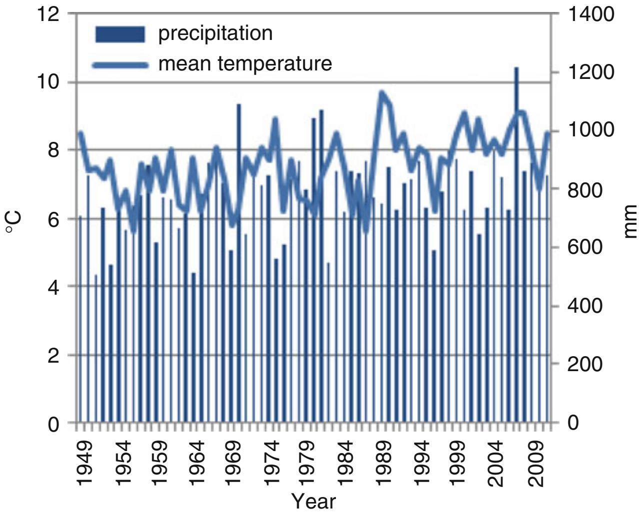

Fig. 1 Average annual air temperature and annual precipitation in Kaliningrad (According to data from the Federal Service for Hydrometeorology and Environmental Monitoring)

maximum value of 9.7 °C in 1989. The annual amount of precipitation in 2007 reached a record for the entire period of observation of 1,214 mm.

Between the fourteenth and nineteenth centuries, there were observed temperature anomalies and abnormal humidity conditions: a cold winter in 1322/1323 with a frozen Baltic Sea, a great drought in 1427 and 1474, very warm summers in 1506 and 1832 in which fruit trees bloomed two times, and a very cold summer in 1832 with a late frost in July. Figure 1 illustrates the current climate development in the region of Kaliningrad.

In the South Baltic region, according to data from the weather stations in Kaliningrad (Russia) and Rostock (Germany) for the last 30 years, the coldest temperature values were observed in 1980, 1985, 1987, 1997, and 2010, and the warmest years were 1983, 1989, 2000, and 2007 (Fig. 2).

Abnormally wet years were observed in 1970 and 2007 and abnormally dry years in 1982, 1996, and 2002. According to the meteorological station in Königsberg/Kaliningrad, changes were also observed in the average surface air temperature in the first decade of the twenty-first century (1901–1910); the positive deviation from the mean average in January was from 0.3 °C to 2.0 °C and in April, July, and October was +2.3±0.2 °C above, confirming the positive trend, which is particularly evident in spring and summer.

The trend of a decreasing frequency in the category of "normal" in the aridity index, beginning in the second half of the twentieth century and continuing until the 1990s, was replaced by a counter-tendency in the beginning of the twenty-first century (Table 1). In the same period, the number of years (40 %) characterized by high aridity dramatically increased, thus affecting the risk factors in agriculture. Moisture deficiency in the beginning of the growing season (April–May) negatively

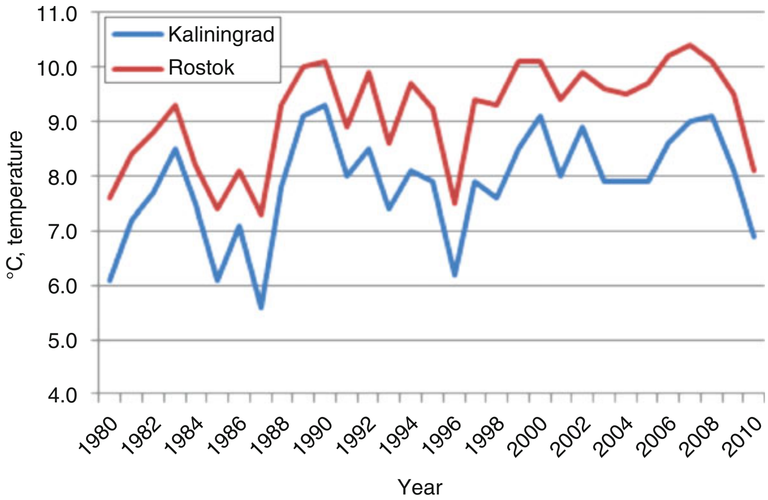

Fig. 2 The average annual air temperature (°C) in Kaliningrad and Rostock (According to data from the Federal Service for Hydrometeorology and Environmental Monitoring 2012; Deutsche Wetter Dienst 2012)

Table 1 Recurring atmospheric aridity index (S) by decade in May

Period	Normal (%)	Too wet (%)	Arid (%)
1950–1959	90	10	0
1960–1969	60	30	10
1970–1979	40	30	30
1980–1989	30	20	50
1990–1999	60	20	20
2000–2009	50	10	40

influences the growth and development of most crops, so the observed trend could be dangerous. A solution to the problem may be found in dual regulation of the water regimen: drainage and irrigation. Table 2 shows the combination of agroclimatic conditions and the yield.

Agroclimatic conditions of crops growth are characterized by the duration of the growing season and the amount of accumulated temperatures during this period. According to the long-term average in the Kaliningrad region, the sum of temperatures for the period with temperatures >5.0 °C was 2,200 °C, and the duration of the period was 201 days. For the period 1980–2010, there was a markedly significant fluctuation in the duration of the growing season and the amount of heat. Combined with the moisture regimen, this is reflected in the varying yields of cereals (wheat) and perennial grasses. The index of aridity of the atmosphere (S) (the ratio between air temperature and precipitation) showed a significant interannual variability. Therefore, 2002 was characterized by an aridity index in May of 3.7, with the amount of heat during the growing season being 2,940 °C, and low yields of wheat and perennial grasses: 23 and 15.3 hwt/ha, respectively (Table 2).

Table 2 Indicators of vegetation conditions in abnormal years

Year	Precipitation (% of the norm)				Deviation of the temperature from the norm				Aridity index					Yields (hwt/ha)	
	IV	V	VI	VII	IV	V	VI	VII	IV	V	VI	VII	VIII	Perennial grasses	Wheat
2002	65	53.9	104.4	55.6	2.0	4.4	1.2	2.4	2.0	3.7	0.9	2.5	5.0	15.3	23
2007	52.7	269.4	145.2	232.3	1.7	1.8	2.2	−0.1	2.1	−2.0	1.0	−2.7	−0.2	20.0	29
2008	130.5	28.4	78	66.4	2.1	0.4	1.0	1.2	0.7	1.6	1.3	1.5	−0.4	21.8	44.8

hwt/*ha* yield capacity per hectare; IV, V, VI, VII, and VIII refer to months

The highest wheat yield in a single year was in 2008, when the total accumulated air temperature was 3,029 °C and the growing season was the longest. The highest wheat yield was observed from 2005 to 2009, with accumulated temperatures from 2,900 °C to 3,055 °C (Figs. 3 and 4).

At the same time, the areas of perennial grasses were reduced due to the high temperatures and high aridity index.

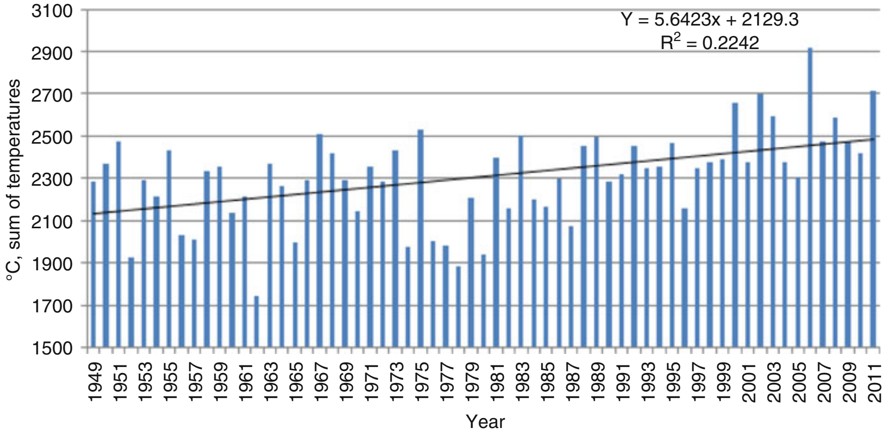

Fig. 3 Total accumulated temperatures for the growing season in Kaliningrad

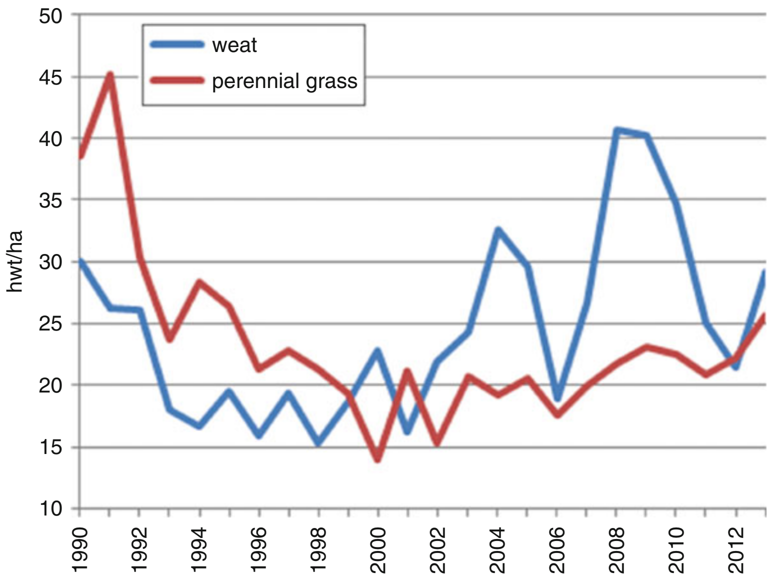

Fig. 4 Crop yields in the Kaliningrad region (hwt/ha). *hwt/ha* yield capacity per hectare

Long-term dynamics of crop yields reveal that, with the intense warming from 2000 to 2009, a substantial growth in wheat yields was achieved compared with the previous decade. In contrast, the growth of perennial grasses was abundant in cool and wet years (Figs. 1 and 3). Analysis of hay yields on the floodplain meadows (Romanenkova 2008) also shows that the temperature has a significant cumulative effect.

In connection with climate change (Roger and Pielke 2005; Fedoroff et al. 2010; Eckersten et al. 2012; Fedorov and Krasnov 2012) and rising accumulated temperatures in the Kaliningrad region, there is the possibility of introducing thermophile plants (in particular soya), both as rotation elements and as crops used for the expansion of production areas. At the same time, considerable interannual air temperature fluctuations and snowless winters pose a risk for the cultivation of winter crops. In winter 2010, for example, the average January temperature reached -8.10 °C, the lowest average in the preceding 20 years, causing a loss of about 70 % of the winter rapeseed crop, which has been actively introduced in the rotation since 2000 and covered about 20 % of arable land in 2009.

Therefore, a prerequisite for increasing the profitability of agriculture in the current climate conditions in the South Baltic area should be conversion to other crops such as perennial legumes and grasses that are resistant to temperature changes. This could increase the duration of the grazing season and reduce the nutrient load of the water by reducing the doses of organic fertilizers required for annual crops.

Meanwhile, one can say for certain that the increasing negative impacts of climate change enhance the frequency of extreme and unpredictable situations (Lobell et al. 2011). Official statistics show that the frequency of freak weather (such as heavy cloudbursts accompanied by floods, frequent heavy storms, etc.) has increased in the Kaliningrad region. This of course raises the question of what to do given the effects of climate change. The first approach could be to examine the features of natural resources in the Kaliningrad region taking into consideration the current phenomena of climate change (Chistyakov 1997; Drozdov and Smirnov 2011). The materials for the study are based on data relating to the near-surface air temperature and precipitation in the Kaliningrad station for the period from 1949 to 2010 and the anomalies of temperature and precipitation calculated as deviations from the long-term average for the period from 1961 to 1990, recommended by the World Meteorological Organization as the basis for such calculations.

The main air temperature trends in the southeastern Baltic coast are comparable with trends observed in the average temperature of the Northern Hemisphere (temperature rise in the last quarter of the nineteenth century; rapid temperature rise in the last decades of the twentieth century). Globally, there are an increasing number of natural disasters involving hazardous meteorological or, more precisely, hydrometeorological processes (storms, strong winds, very intense rainfall, floods, glaze effects, etc.) as well as rigors of temperature (extremely high temperature values, increasing forest fires, higher incidence of heat waves and droughts, etc.). Linear trends in air temperature reveal a sharp rise in temperature and a rise in its variability from year to year. Climate warming in the late twentieth and early twenty-first century exceeds the rate of increase during the rest of the twentieth century by far (Jacob 2005; Kyslov et al. 2008; Getzlaff et al. 2011). Analysis of changes in annual precipitation values during the study period also reveals a significant positive trend, namely, an average growth rate of 20 mm within 50 years, an additional symptom of global warming. An essential feature is the increase in the amplitude range of precipitation beginning in the late 1970s. Of considerable interest is a large asymmetry in the number of positive and negative deviations of air temperature during the study period: the number of positive deviations is two times higher than negative deviations. The largest positive deviations, exceeding the value of 1.5 °C, were observed in 1975, 1989 (the warmest year of the twentieth century), 1990, 2000, 2002, 2006, 2000, and 2008. The largest negative deviations were observed in 1956 and 1987 (the coldest years). Air temperature anomalies, calculated as deviations from the average for the 1961–1990 period, ranged from −1.5 °C to 1.5 °C. The highest average annual temperature abnormality of 2.5 °C was seen in 1989. In the past decade there have been several record temperatures that had not previously been observed in the history of meteorological observations (Fig. 5). The annual air temperature in 1989, 1998, 2007, and 2008 exceeded the normal values by 9 °C. The maximum air temperature was 12.6 °C in January and 34.6 °C in July 2007. In July 2010 a maximum value of 33.8 °C was reached.

The average air temperature (the norm), defined for the period 1961–1990 in Kaliningrad, was 7.2 °C. However, the last quarter of the twentieth and the beginning of the twenty-first century are characterized by a significant increase in the surface air temperature (Fig. 5). For example, the average annual air temperature measured over the decade from 1991 to 2000 increased by 0.9 °C compared with an average of 7.8 °C in the decade from 1961 to 1970. In 1989, there was a maximum average annual air temperature of +9.7 °C. A high average annual temperature exceeding the “norm” by 1.5–2 °C was observed in 1990, 2000,

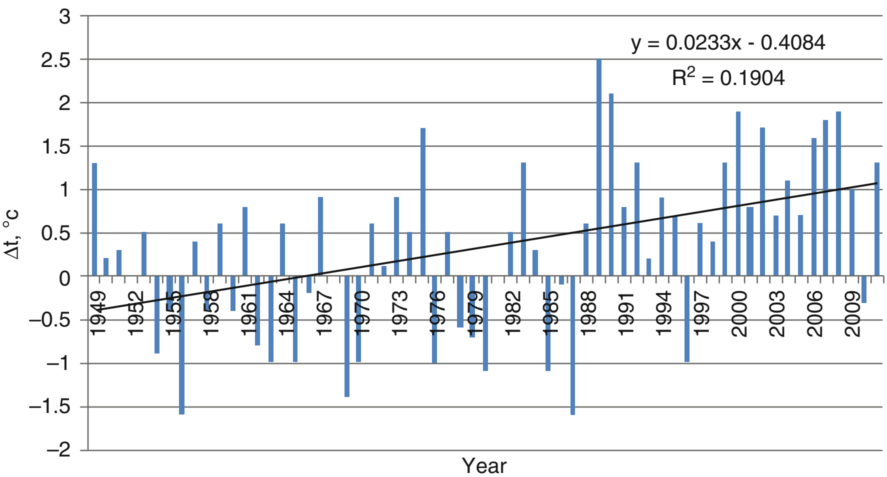

Fig. 5 Deviation from the norm in air temperature in Kaliningrad

2002, 2004, and 2007. This very strong warming is typical for the autumn–winter period; the speed of summer temperatures rising is lower.

The beginning of the study period is characterized by negative deviations from the long-term average precipitation level. In the late 1970s there was a change in the rise of precipitation values (Fig. 6). In general, noticeable sharp fluctuations could be observed from year to year for the period of investigation. In 2006, for example, rainfall levels were almost two times lower than in 2007, which was characterized by wet weather during the entire study period with 1,214 mm of precipitation. This can be compared with the rates of deviation in rainfall for the two 30-year intervals, namely, from 1949 to 1979 and from 1980 to 2009. In the first period, especially at the beginning of the period, there were more frequently observed adverse deviations, whereas in the second period there were years in which the rainfall exceeded the normal rate by threefold.

The graphs in Figs. 5 and 6 show clearly visible sharp short-period fluctuations that characterize the interannual variability of temperature and precipitation. Seasonal variability of temperature is also quite evident. Comparing the monthly average and the annual air temperature for the two 30-year periods observed, we can record the following fact: the average annual temperature for the last 30 years (1981–2010) is higher by 0.8 °C than for the period with normal values (1961–2010). As can be seen, the speed of the trend differs in some months: the most intense warming occurs during the winter and spring months, and the most significant warming is evident for January and February. The average temperature in the last 30 years has increased by 1.7 °C to a value of 1.4 °C in February.

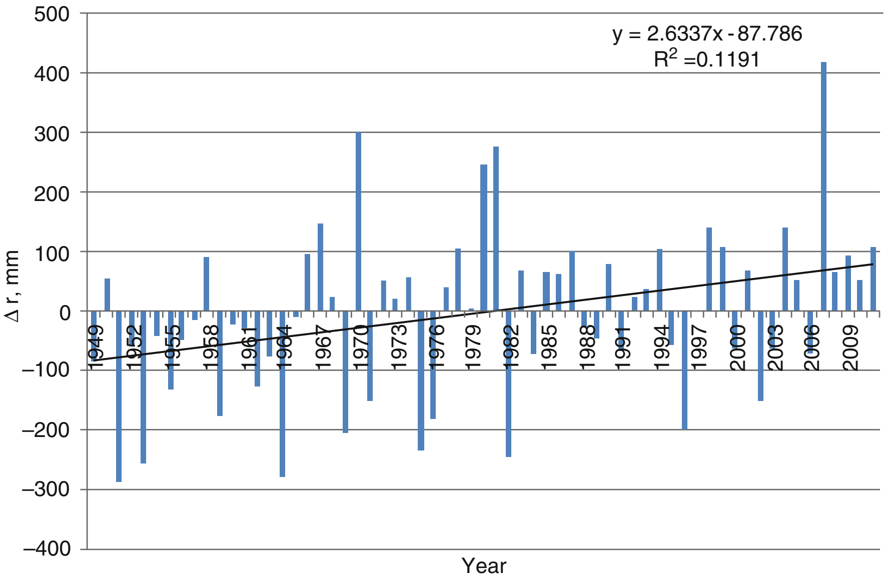

Fig. 6 Deviation from the norm in precipitation in Kaliningrad

In summer and autumn, the rate of warming is reduced, especially in June, September, and October. In the last 30 years of abnormally warm winter seasons, mild spring temperatures have become more frequent than cold ones in Kaliningrad. As a result, a comprehensive statistical analysis of long-term climate indicators makes it clear that during the study period there were sharp fluctuations in both temperature and precipitation. Variability of extreme temperature indices for the period 1949–2011 is shown in Fig. 7. As can be seen, the maximum amplitude of the oscillations of air temperature is characteristic of the winter months. In January, the lowest temperature was observed in 1956 (−32.5 °C) and the highest in 2007 (12.7 °C); the range of variation was 45.2 °C. During the summer, the oscillation amplitude of extreme values of air temperature is significantly reduced and is about 32 °C. It is noticeable that the lowest temperature in all seasons of the year can be observed until 2000, whereas the highest temperature could be fixed to three times, namely, in January 2007, April 2000, and December 2006.

In recent decades, there have been some maximum values that had not occurred in the previous history of the observations, with comparable positive annual temperature anomalies. In Kaliningrad, the mean annual air temperature amounted to 9.2 °C in 1989 and 9.3 °C in 1998.

The growth of weather variability:

- The number of severe weather events and associated risks: strong winds, very heavy rainfall, and rising of water levels in the rivers above alarming marks.
- Since most precipitation falls as rain rather than as snow and water seeps faster, the soil absorbs less moisture than with a melting snow cover. This has a negative effect on the moisture balance, leading to more erosional activity.

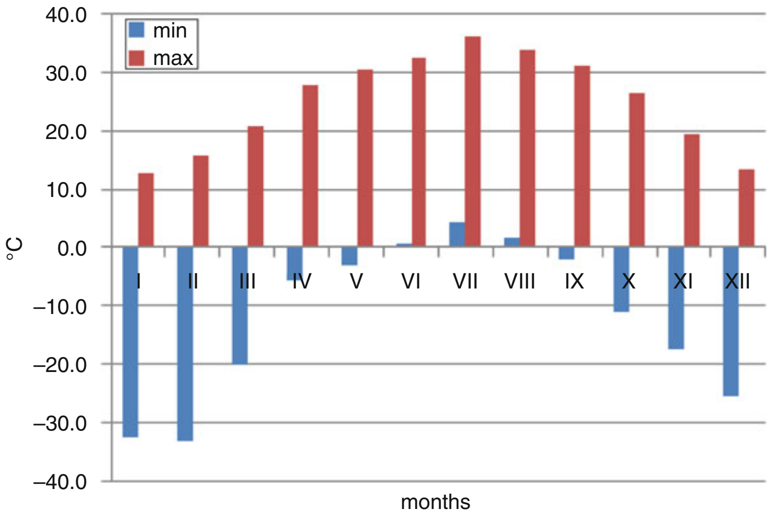

Fig. 7 Extreme maximum and minimum air temperatures for the period from 1949 to 2011 in Kaliningrad

- In western Russia, dramatically higher river flow rates are expected up to 2015. This will lead to lower soil freezing due to a rise of groundwater levels and poor drainage capacity.

As the region of Kaliningrad is situated in the west wind belt, westerly, southwesterly, and southerly winds predominate in various meteorological manifestations with diverse effects. Above all, in autumn and winter intense low-pressure systems can sweep across the Baltic Sea in the form of heavy storms causing floods and other damages. Environmentally negative impacts can also occur such as transboundary contamination (sulfur oxides, nitrogen oxides, heavy metals, etc.).

The most frequently measured speeds during storms are 12.5–15.2 m/s (52.9 %) and 15.3–18.2 m/s (21.4 %). Winds with a speed of more than 8 m/s occur in 13 % of all cases. This is a problem as unfavorable conditions for treating agricultural crops with pesticides occur.

Analysis of the Impacts of Climate Change

In connection with climate change, there are also negative effects affecting human and animal health. For example, infections such as Lyme borreliosis (Lyme disease) that have been by no means unusual in the Kaliningrad region spread more and more like an epidemic. Thus, the increase of ticks creates a critical situation when cattle are kept in outdoor husbandry systems in the Kaliningrad region. Human infection may occur through tick bites as well as by drinking the milk of infected animals. Table 3 provides an overview of tick-borne morbidity.

Table 3 Regional specificity of the morbidity of tick-borne encephalitis and Lyme disease during the period from 1999 to 2008

	Morbidity (per 100,000 population)				
	Tick-borne encephalitis			Lyme disease	
Year	Kaliningrad region	Karelia region	Belarus	Kaliningrad region	Belarus
1999	1.3	4.4	0.3	8.2	1
2000	1.2	5.6	0.2	19.9	1.9
2001	1.2	6	0.6	7.8	1.8
2002	1.2	7.2	0.2	7.2	1.8
2003	3.8	15.2	0.5	22.7	5.1
2004	1.3	11.6	0.4	13.3	5.2
2005	1	9.2	0.5	13.2	5.4
2006	0.9	7.6	1.1	20.9	9.1
2007	0.8	8.8	0.8	20.8	6.7
2008	0.8	–	0.7	12.5	6.6
Annual mean	1.4	8.4	0.5	14.6	4.5

Long-term analysis of natural focal infections of the population (1999–2008) detects different trends in the number of victims in some regions of Russia and the world, including the Kaliningrad region (Barinova and Kochanowskaja 2011). Also, the morbidity of tick-borne encephalitis in the Kaliningrad region for the period under review decreased from 1.3 per 100,000 population in 1999 to 0.8 in 2008. A similar trend is observed in Karelia. In Belarus, the spread of tick-borne encephalitis as well as Lyme disease also has a tendency to increase (Table 3). This may be associated with an increase in winter air temperatures and, at the same time, an increased frequency of extreme weather conditions. Growth in the number of insect pests increased pesticide use. A long-term analysis of natural focal infections among the population provides evidence that there is a connection between the high frequency of morbidity, particularly in encephalitis, and high temperatures. Thus, in 2003 and in 2010, the morbidity values were clearly higher than in previous years, and it was that summer in which the temperatures were the highest measured since the beginning of weather records.

Growth in the number of insect pests and diseases of plants depends on the following factors:

- Measures need to be improved to keep pests in the soil during the winter.
- High humidity, high frequency of surface inversions, weakening of the wind in the second half of the growing season, and air stagnation cause the growth of fungal diseases of plants.
- Cultivation is sensitive to weather variability in monocultures (corn, rape).

New Uncertainties and Needs

In the context of climate warming, a relatively large impact is expected on the productivity and structure of agroecosystems; forest biotic communities; the quality of agricultural, pastoral, and forest land; the spread of diseases; and the survival of some wild plants, domestic animals, and cultivated plants. For the Kaliningrad region, one has to face up to major challenges relating to climate change and measures that are suited to mitigate at least the most dangerous effects need to be proposed (Table 4).

The structure of rural landscapes has changed when viewed in the context of natural and agricultural factors that, unfortunately, have not necessarily had desirable effects. The invisible chemical changes in connection with pesticide use, the continuing urbanization process, and even the military activities are the negative and yet dramatic consequences. Total forest coverage is now no more than 17–18 %. Deforestation is probably the biggest environmental problem for the Kaliningrad region. However, to stop cutting the forests down is nearly impossible without the political will of regional and federal decision makers.

Another environmentally harmful example is the planting of crops without using rotation to avoid soil degradation. Thus, rapeseed is sowed over several years.

Table 4 Adaptation of land use management to climate change in the Kaliningrad region

Type of nature management	Challenge	Adaptation
Agricultural	Increased frequency and variability from year to year of severe weather events (storms, frosts, droughts, storms)	Restore drainage
	The danger of erosion processes	Regulation of the soil water regimen (including bilateral) on the polder lands
	Loss of humus, soil salinity increased	Selection of thermophile crops
	Increased risk of infectious and parasitic diseases of plants and animals	Increase the area of meadows
Forestry	The loss of forests	Increase forest area up to 25–30 % with the introduction of broad-leaved trees
	Water logging, changes in groundwater levels	
	Growth pathology of tree crops	
	Expansion of distribution ranges of tick-borne encephalitis	Pathology monitoring

The abovementioned negative processes occur because of a lack of collaboration for various reasons. Being ready to start dialogue with different groups of society is a prerequisite to generate an institutional and social consensus to preserve the natural foundations for both humans and animals.

Pollinator's Drama

The almost complete anthropogenic transformation of nature in the Kaliningrad region – like in most countries of the Baltic region (Palang and Ryden 2003) – has resulted in only a small remnant (not more than 18 % nowadays) of an originally widespread forest area, thus creating one of the major problems in agriculture and forestry, namely, a small number of pollinators, in particular bees. In addition, the increase in precipitation and intraday fluctuations in temperature during the winter also cause a decrease in the bee population (Gaeva and Barinova 2013).

Documentary sources in East Prussia mention beekeepers for the first time in 1367. From this year on, free hunting, fishing, and beekeeping were allowed. Everything that was found in the forests or that could be caught in the rivers was allowed to be sold, but the authorities set stringent prices for honey. Furthermore, each beekeeper could possess part of the forest. On the trunk of a tree inhabited by bees, the beekeeper (or "bee hunter") marked a sign by cutting a square, cross, crescent, etc. As the parts of the forest with good honey yield were mostly to be found on the edges, within clearings, and burnt areas, beekeepers often set fire to the young forest. Beforehand, the hives were gathered up and put in a suitable place with a ditch dug around it. Later, in the fifteenth century, due to frequent uncontrolled fires, a law prohibited forest burning after 8 April, when the dry season began. From the mid-fifteenth century onward, anyone who lived in the forests of Prussia had to obey the laws and pay taxes – apiaries in the gardens around the houses, however, were exempt from taxation and, thus, from that time on, hives were moved from the forests into the villages.

The "rules for bee hunters" stipulated penalties for those persons who damaged hives and who failed to act in case of fire. By law, beekeepers had to keep forest areas in order, and in case they did not know how to cut down or burn wood in their territory, they had to repair any possible damage.

In the middle of the nineteenth century, there was quite high productivity in beekeeping in East Prussia. In 1773, in the area around Schlohauer, a beekeeper was given 507 thalers for the production of honey in comparison with 14 thalers given as profit from the sale of timber harvested in the same piece of forest.

However, as early as the nineteenth century, a decline of beekeeping took place because of the war in 1812 and adverse weather conditions in later years (cold winters in 1824/1825, 1844/1845, and 1848/1849).

Moreover, in the middle of the nineteenth century, active deforestation began. All trees with hollows were allowed to be cut down. Yet, according to estimates, at the end of the nineteenth century, one single hive yielded 13–20 kg of honey per year. Over the 48 years from 1864 to 1912, the number of bee colonies in East Prussia increased from 85,168 to 186,644.

The distribution of bee colonies in East Prussia (with distribution in the Kaliningrad region after 1945 in brackets) was as follows: in 1907, 4.3 beehives existed on 1 km^2 (5.9 beehives on 1 km^2 of farmland), and in 2010, 5.9 beehives existed on 1 km^2 (2.5 on 1 km^2). In 1938, there were 244,024 beehives in the whole of Prussia and 96,757 in East Prussia (in 1943, there were 88,000 bee colonies); the average productivity of bee colonies was 30 kg of gross honey and up to 10–15 kg of salable honey (Hansen 1916; Bloech 1932).

During the Second World War, honey production almost came to a stop, but in the first years after the war, in the newly established collective farms, specialists began to restore beekeeping.

Before the Second World War, the European dark forest bee (*Apis mellifera mellifera*) was prevalent. This bee species was well adapted to the cold and wet climate: their natural habitat extended from the tundra to the steppes. In the postwar period, a new bee species, the gray Mountain Caucasian bee *Apis m. caucasica*, was introduced, and the Carpathian bee *Apis m. carpatica*, bred in Maykop, was imported to the Kaliningrad region. These breeds of bees did not tolerate long winter periods (over 4 months) or high humidity, and crossbreeds with local bees were often susceptible to infectious diseases and proved unproductive. Uncontrolled importation of unadapted species of bees to the Kaliningrad region led to the loss of local bee populations, which were more adapted to the habitat, especially to the cool climate.

Finally, 50 or 60 years later, more than 5,000 bee colonies were killed through fungal infections and the first reports of the tick-borne disease varroa appeared. In the 1990s, beekeeping in the Kaliningrad region fell into decay. Apiaries were destroyed or subdivided among private owners. According to the National Agricultural Census held in 2006, the number of bee colonies totaled 14,000 in the Kaliningrad region, but by 2008 there were only 6,588 registered bee colonies left. According to our data, approximately 20,000 beehives show no more than an average productivity of 15–20 kg of honey per family. Thus, beekeeping can be classified as an informal sector in agriculture. A significant problem lies in the fact that there is a lack of annual records of bee colonies, especially of the morbidity of bees and their intoxication by pesticides in different areas of the Kaliningrad region.

The increase in the use of high doses of pesticides (Fig. 8) is a threat to wild pollinators (wild bees, bumblebees) and to populations of honeybees (*Apis mellifera*) in agro-geosystems. In order to control pests, farmers now use registered insecticides that are toxic to bees from the class of neonicotinoids. According to environmental restrictions on the use of this kind of substance, regulations on temperature and spatial isolation within 5 km of the honeybee (*Apis mellifera* L.) have been established, but solitary bees are not covered (Dixon 2003; Tyliniakis 2013; Burke et al. 2013). Evidence of a negative impact from the use of neonicotinoids on entomophilous crops has been found. Processing of wheat crops in a farm leads to the death of solitary bees and to a lack of pollinators, even in neighboring farms, and to a ten times higher reduction of yields of sunflower and alfalfa (Artohin et al. 2013). Under such conditions, controlled pollination of cultures is only possible with the help of honeybees.

Modern beekeeping is an agricultural branch, engaged in breeding honeybees for beeswax and other bee products as well as for the pollination of crops in order to increase their productivity. The main challenge for beekeeping is based on its environmental and economic efficiency for specific regions. As the demand for environmentally friendly products is still high, beekeeping requires suitable regions

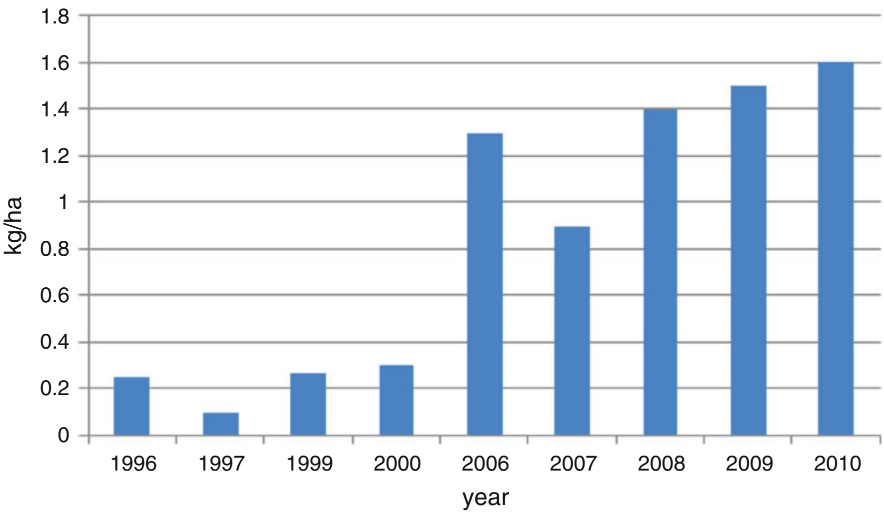

Fig. 8 Pesticide use on arable land in the Kaliningrad region (kg/ha)

to be found for honey production, as well as exploring the possibility of combining crops, livestock, and beekeeping in the same area without any of these inflicting damage on any of the others.

Modeling of Climate-Dependent Events in Agriculture

Mathematical models and system analysis of data play a more and more decisive role in the environmental sciences against the background of regional climate change and its consequences for agricultural development.

Methods of mathematical simulation describing the Pregel river basin (the main drainage basin in the Kaliningrad region) were presented as a balance system of differential equations where a variety of variables relating to the different components of a climate system such as temperature and precipitation and elements of vegetation such as forested area and cultural phytomass, soil humus, etc. (Zotov 1997) are put in. Retrospective experiments were conducted using data from the years 1960 to 1989 (showed the sufficient exactness).

Scenarios in a model with climate warming [average annual temperature (T) = 9 °C] show a significant increase in the forest and agricultural phytomass (10–15 %) with the level of underground water going down. In scenarios with a colder climate (T = 5 °C), the variable quantities showed the opposite trends.

By generating development models we have the possibility to calculate the quantitative character of changes in agroecosystems. So, for a change in forest phytomass, humus, and nitrogen content in the soil dependent on climate change, more than 100 years will be needed, and for the regeneration of soil humus, more than 1,000 years will be needed, whereas for 1-year crop phytomass, production under new climatic conditions only 1 year of data will be required.

Nitrogen content in river water reacts to climate change (increase of precipitation) in a similarly sudden rapid way (i.e., a sudden leap). The use of mineral fertilizers is the main cause of water nitrogen pollution. If we increase the normal level of fertilizers by two to four times, the nitrogen content in underground water grows at a rate of between 1.3 and 1.5 times and in river water at a rate of between 2.0 and 2.5 compared to the norm. It is evident that the eutrophication of Baltic coastal bays and lagoons will continue without changes in the management of agriculture.

In scenarios with an increasing forested area (and other equal conditions), the content of nitrogen in waters is decreased, whereas the level of underground water grows in such a negative way that the Kaliningrad region registers a historical excess of moisture.

Increased drainage of farmland is leading to a decrease in the groundwater level, but the surface nitrogen flow is growing. So, in order to reduce the complex negative environmental consequences, it is necessary to use the right complex method for modeling climate-dependent parameters.

For example, a scenario with a four- or fivefold increase in the application of organic and mineral (nitrogen) fertilizers compared to the former level, an increase in land drainage by 10 %, and an increase in woodland to a level 1.5 times higher than before ended with the best results, namely, an increase of cultural phytomass production and soil fertility on the one hand and a decrease in the nitrogen content of surface water and in the groundwater level on the other hand.

The most significant aspect of balanced land use in agriculture is the creation of natural space differentiation in accordance with environmental (including meso-climatic) conditions. To achieve this, it is important to consider the landscape–basin approach, in which the area model is described in relation to elementary landscape–basin systems. The model also has to include the space changes in local climate caused by rivers, lakes, the coastal zone, etc. (Orlenok et al. 2000).

To define the causes of excessive moistening of sandy soil in the Curonian Spit, the "meteofactor-level regime of subterranean waters" model was used. The following parameters play a significant role: the coefficient of filtration, the average viscosity of underground waters, the duration of filtration of the soil horizon, the initial level of underground water, and the position of these levels on the borders between the sea and the lagoon.

On the basis of the model calculation, there was a fixed time for water coming to the surface on the low parts of the sand spit in connection with the intensity of filtration and its position to the earth surface. Such a forecast can help to organize protection against erosion and destruction of the spit by the outcropping of subterranean waters in a timely fashion (Korneevets 1998).

These scenarios are based on the knowledge of modern natural processes and the mechanisms of their effects that are possible under the current system of wildlife management in the Kaliningrad region. For example, in the next 15 years, along with a continued growth of the mean annual air temperature and annual precipitation, the waterlogged area of the farmland could grow by 15–20 %. On the flat plains with poorly drained soil, the moraine ridge on upland plains along with the current trend of deforestation will exacerbate the risk of erosion, the rise of groundwater levels, and the flooding of low landforms. Adverse climate conditions, especially in the form of an increase of precipitation in the South Baltic area as described in the REMO is regional climate model with horisontal resolution 50*50 km scenario for the period between 2020 and 2029, could lead to an expected increase by 15–20 % compared with the norm of 800 m. According to the model that HIRHAM projected for the South Baltic, winter temperatures will range between 4 °C and 5 °C during the period from 2071 to 2100. In the Gwardejsk District (Kaliningrad region), the area of waterlogging and flooding of arable land had increased by 43 %, hayfields by up to 46 %, and pastures by up to 40 % by 2008. If current trends continue for 15 years from 2008, i.e., by 2023, the flooded area and waterlogged arable land will increase by up to 47 % (corresponding to 10,800 ha), hayfields by up to 48 % (4,625 ha), and pastures by up to 48 % (6,620 ha). It should be noted that there is a current increase in flooded agricultural land, especially arable land. The results of a survey of overgrown farmland show that by 2009, the Kaliningrad region had undergone an increase of scrubby parts of arable land by 5.2 %, of grasslands by 15.8 %, and of pastures by 17.6 %.

Geoinformational Databases: A New Strategy in Agricultural Management

A geoinformational database is a necessary aspect of regional environmental management. It is an ecological cartography and regionalization, modeling and prognosis. The cartography may be complex and branch out in different directions and reflects spatial temporal coherence (maps and atlases characterize the areas and estimate the state and reproduction of bioresources). The relationship between the climate, biosphere, and environment and the increasing adverse human influence on the ecosystem require a systematic and methodical approach. It is necessary to estimate the conditions of natural and economic activities and their effects. To provide the composition and quality of geoinformation, models and expert values are needed to build a system that is best adapted to changing environmental conditions.

Conclusion

With the current state of knowledge, we cannot exhaustively estimate the negative impacts of climate change from a quantitative and qualitative point of view; however, we can assume some of the possible consequences. Regarding the Kaliningrad region, we should consider the following factors of climate change:

- An increase in the average air temperature
- Changes in the amount and patterns of precipitation
- A shift of agroclimatic zones to the north
- An increased atmospheric aridity
- An increased frequency of severe weather events (storms, hail, floods) occurring more or less frequently over the years

The rational use of agricultural landscapes under conditions of climate warming is a combination of arable land with seminatural areas (Tishkov 2006). The use of waterlogged and flooded areas as meadows will reduce the leaching of the soil. Reducing the crops that are sensitive to fluctuations in temperature and humidity and that require multiple treatments with pesticides will help to stabilize the size of pollinator populations.

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Climate Change and Agricultural Adaptation in South Asia

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Contents

Abstract

The chapter elaborates the adaptation initiatives undertaken by farmers in South Asia, and advocates the need for strong policies to support agricultural adaptation. It elicits the farmers' perceptions and adaptation measures toward climate change and extent of adaptation through computing an index and

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supports strong extension and policy initiatives to enhance agricultural adaptation for combating food insecurity. It has identified the fact that rises in temperatures, decreases in rainfall, and frequent incidences of pests and diseases are the common perceptions of farmers toward climate change, both for drought and floods. Adaptation measures practiced by farmers' for drought are buying insurance, change in planting dates and planting times, work as labor, and construct water harvesting structures. For floods, early sowings, saltwater spray for harvested paddy stalks, strengthening of riverbanks, and improved drainage are the adaptation measures.

Keywords
South Asia • Climate change • Perceptions • Adaptation measures • Policy

Introduction

The impacts of climate change on agriculture are being witnessed all over the world, but countries especially like India in South Asia are more vulnerable in view of the large population depending on agriculture and excessive pressure on natural resources. Rainfed agriculture is likely to be impacted severely in view of its high dependency on monsoon and the likelihood of increased extreme weather events due to aberrant behavior of southwest monsoon in this part of the world. While reducing the greenhouse gas emissions holds key in addressing the problem, successful adaptation to climate change is important to stabilize the productivity. Adapting to climate change is a continuous process, and communities have wealth of information. Climate change is becoming a major driver of disasters, with increasingly frequent and intense floods and storms affecting more people globally. Increased forced displacement is an extremely likely consequence of such events. Heightened drought risk, desertification, sea-level rise, and changes in the availability of water and fertile land, coupled with reduced access to basic resources, will also fuel longer-term migration and forced displacement. As a first step, there is a need to document all the indigenous practices farmers have been following over time for coping with climate change. A better understanding of the farmers' perceptions toward climate change, the practices they adopt, and the factors that contribute to the decision-making help in formulating policies and programs aimed at minimizing the losses and reducing the risk due to climate variability and change. Understanding how and why farmers have responded to climatic change is a necessary step to informing how to support current and future adaptation.

Climate Change Impacts on Agriculture in India

Agriculture is one of the largest contributors to India's gross domestic product (GDP), approximately 20 %. It is the main source of livelihood for almost 60 % of the country's total population. The impacts of climate change on agriculture will therefore be severely felt in India. It has been projected that under the scenario of a 2.5–4.9 °C temperature rise in India, rice yields will drop by 32–40 % and wheat yields by 41–52 % (GOI 2011; Guiteras 2007; OECD 2002). This would cause GDP to fall by 1.8–3.4 %. Despite the gloomy predictions about the negative impacts for India's agricultural sector, changing climate is expected to bring opportunities as well, e.g., production gains through the CO_2 fertilization effect or the expansion of cultivated land to higher altitudes and northern latitudes. The share of Indian livestock in the GDP is about 7 %. Indian livestock are responsible for about 54 % of total methane emission in India. Increasing sea and river water temperature is likely to affect fish breeding, migration, and harvests. A rise in temperature as small as 1 °C could have important and rapid effects on the mortality of fish and their geographical distributions, and hence climate change effects could be very significant for fisheries (Climate Change and 12th Five Year Plan 2011).

Agricultural Adaptation to Climate Change

Food production is vulnerable to climate shifts because crops and cropping systems are adapted to local conditions: slight perturbations such as temperature fluctuations at critical points in crop development can have substantial impacts on productivity (Hatfield et al. 2011). Climate change also threatens the long-term capacity for food production through increased soil erosion and reduced soil fertility (Lal et al. 2011). The certainty of increased need for food to feed a burgeoning global population and the uncertainty of the short- and long-term impacts of climate change on agriculture combines to make efforts to enhance the resilience of agricultural systems a top societal priority (IFPRI-International Food Policy Research Institute 2010). The recognition that climate change-related threats to agriculture also represent threats to quality of life on a global scale has led to an increasing amount of attention to adaptation and mitigation strategies for agriculture (e.g., Howden et al. 2007; McCarl 2010). Calls for adaptive action have acknowledged that farmers are both among the most vulnerable groups to climate change and the ones on whom the task of adapting to climate change and mitigating agriculture's contribution to it largely falls (Berry et al. 2006). At the same time, farmer willingness and capacity to respond to climate change is a social process based on the social construction of the risks and vulnerabilities of increasingly variable climate conditions. The farmer is a critical decision maker if agricultural lands are to be effectively managed to adapt to changing climate conditions (Gordon et al. 2013).

Agriculture in developing countries is one of the most vulnerable sectors of the global economy to climate change (Kurukulasuriya et al. 2006; Seo and Mendelsohn 2008a). Farmers whose livelihoods depend on the use of natural resources are likely to bear the brunt of adverse climate impacts. Farmers will be hard hit if they do not adjust at all to new climates (Mendelsohn et al. 1994; Rosenzweig and Hillel 1998; Reilly et al. 1996). Adaptation to climate change requires that farmers first notice that climate has changed and then identify useful adaptations and implement them (Maddison 2006). Adaptation is widely recognized as a vital component of any policy response to climate change. Studies show that without adaptation, climate change is generally detrimental to the agriculture sector, but with adaptation, vulnerability can largely be reduced (Easterling et al. 1993; Reilly and Schimmelpfennig 1999; Smit and Skinner 2002). The degree to which an agricultural system is affected by climate change depends on its adaptive capacity. The adaptive capacity of a system describes its ability to modify its characteristics or behavior so as to cope better with changes in external conditions. Adaptive capacity is determined by various factors including recognition of the need to adapt, willingness to undertake adaptation, and the availability of, and ability to deploy, resources (Brown 2010). Recent empirical studies indicate that farmers have already adapted to the existing climates that they face by choosing crops or livestock or irrigation (Kurukulasuriya and Mendelsohn 2007, 2008; Nhemachena and Hassan 2007; Seo and Mendelsohn 2008b, 2008c) ideal for their current climate. The adaptation strategies must not be used in isolation. For example, the use of early-maturing crop varieties must be accompanied by other crop management practices such as crop rotation or the use of cover crops. This, however, requires additional institutional support, such as credit and access to input, markets, and information. Information about farmers' awareness of climate change and current adaptation approaches would assist policymakers in their efforts to decrease the country's vulnerability to the adverse impacts of climate change (Deressa et al. 2008). However, limited information exists on the impact, vulnerability, and adaptation to climate change, especially at household levels. Given this knowledge gap, there is a need to carefully evaluate the impact of climate change on rural livelihoods in order to provide authorities with timely information for adaptation strategies.

The objective of the present study was to identify farmers' perceptions toward climate change (both drought and floods) along with their farm-level adaptation measures in South India with a view to suggest appropriate research/policy issues which help in facilitating farmers' adaptation. Role of extension in facilitating adaptation to climate change is discussed.

Methodology

Among South Indian states, Andhra Pradesh was chosen as the locale of this study since (a) the farmers in this region are exposed to a great degree of climate variability resulting in high vulnerability and (b) researchers' familiarity with local language and culture. Anantapur, Mahbubnagar, and East Godavari districts representing three different regions of the state were selected randomly. Anantapur and Mahbubnagar have a semiarid climate with average annual rainfall being

Table 1 Selected study mandals with villages in parentheses, for Anantapur, Mahbubnagar, and East Godavari districts

District	Mandals (villages in parentheses)
Anantapur	Bukkarayasamudram (*Bhadrampally, Siddharamapuram*)
	Chenne Kothapalli (*Nagasamudram, Chenne Kothapalli*)
	Mudigubba (*Podarallapalli, Mangalamadaka*)
Mahbubnagar	Mahbubnagar (*Machanpalli, Appaipally*)
	Kothakota (*Nirven, Palem*)
	Ghatt (*Penchikalapadu, Aragidda*)
East Godavari	Gollaprolu (*Gollaprolu, Chendurthi*)
	Peddapuram (*J.Thimmapuram, Kattamoru*)
	Marredumilli (*Narsapuram, Dora Chintalapalem*)

560 and 600 mm, respectively, whereas East Godavari has a coastal climate with annual rainfall of 1,100 mm. The predominant crops are groundnut in Anantapur; maize, groundnut, and cotton in Mahbubnagar; and paddy in East Godavari district, so the semiarid districts of Anantapur and Mahbubnagar grow dryland crops, whereas the coastal district of East Godavari grows waterlogged crops like paddy. A sample of 180 farmers at the rate of 60 each from Anantapur, Mahbubnagar, and East Godavari districts of Andhra Pradesh in South India were selected randomly. Three mandals (a mandal is a unit of administration above village and below district level in a state and comprises several villages) each from the selected districts, with two villages under each mandal, were chosen randomly. From each village, ten farmers were selected randomly for collecting data. The selected mandals, with villages in parentheses, for the above three districts are given in Table 1. Data was collected using a pretested interview schedule from the farmers along with focused group discussions. Percent analysis and composite index (adaptation index was computed by the formula: adapted measures/total recommended measures × 100) developed in the study were used for analyzing data.

Results and Discussion

Farmers' perceptions and Adaptation Measures Toward Climate Change

From Table 2, it is evident that rise in temperatures followed by decrease in rainfall, advanced onset of monsoon, middle long dry spells, terminal heavy rains, prevalence of pests and diseases, and ITKs for weather forecast failing are the major farmers' perceptions in that order of magnitude regarding climate change in

Table 2 Farmers' perceptions regarding climate change in Anantapur

S. no.	Farmers' perception	Number[a]	%	Rank
1.	Rise in temperatures	57	95	I
2.	Decrease in rainfall	56	93	II
3.	Advanced onset of monsoon	54	90	III
4.	Middle long dry spells	53	88	IV
5.	Terminal heavy rains	50	83	V
6.	Uneven distribution of rainfall thereby affecting length of growing season	49	82	VI
7.	Prevalence of pests and diseases	47	78	VII
8.	Indigenous technical knowledge (ITKs) for weather forecast failing	41	68	VIII

[a]Multiple responses

Table 3 Farmers' adaptation measures toward climate change in Anantapur

S. no.	Farmers' adaptation measures	Number[a]	%	Rank
1.	Buying insurance	56	93	I
2.	Change in planting dates of groundnut (go for early sowings may be between May end to early June)	55	92	II
3.	Intercropping with red gram in 8:1 or 12:1 ratio	48	80	III
4.	Intercropping with castor contemplated	47	78	IV
5.	Construction of water-harvesting structures under Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)	45	75	V
6.	Requiring of quick-maturing, drought-resistant varieties	42	70	VI

Anantapur. Bryan et al. (2009) in their study in Ethiopia and South Africa reported that farmers experienced increased temperature and decreased rainfall. Similar observations were reported by Vedwan and Rhoades (2001), Hageback et al. (2005), and Dejene (2011) in their studies. Results of a study conducted in Bundi district of Rajasthan, India, revealed farmers' perceptions to climate change as increase in temperatures, decreased rainfall, and long dry spells. The chief adaptation measures followed by farmers are change in planting time, intercropping, soil and water conservation, and planting drought-tolerant crops (Dhaka et al. 2010).

Table 3 illustrates that buying insurance, changing planting dates of groundnut, intercropping with red gram, construction of water-harvesting structures, and requiring of quick-maturing, drought-resistant varieties in that order of magnitude are the major adaptation measures followed by farmers toward climate change in Anantapur. This finding is consistent with that of Swanson et al. (2008) who reported that crop insurance was widely used by farmers in Foremost region of Canada (which is similarly dry), and the common feeling was that even though it might not provide sufficient returns for losses incurred, it does offer some

Table 4 Farmers' perceptions regarding climate change in Mahbubnagar

S. no.	Farmers' perception	Number[a]	%	Rank
1.	Rise in temperatures	55	92	I
2.	Decrease in rainfall	53	88	II
3.	Advanced (some places timely) onset of monsoon	51	85	III
4.	Middle long dry spells accompanied by cloudy weather during flowering	48	80	IV
5.	Terminal heavy rains	46	77	V
6.	Prevalence of pests and diseases (powdery mildew, mold in castor; smut and jassids in paddy)	41	68	VI

protection. It has allowed them to continue farming. Agricultural insurance can help people to cope with the financial losses incurred as a result of weather extremes. Insurance supports farmers in their adaptation process and prevents them from falling into absolute poverty. Apart from stabilizing household incomes by reducing the economic risk, insurance can also enhance farmers' willingness to adapt, make use of innovations, and invest in new technologies (Anna et al. 2011). Agricultural adaptation involves two types of modifications in production systems. The first is increased diversification that involves engaging in production activities that are drought tolerant and/or resistant to temperature stresses as well as activities that make efficient use and take full advantage of the prevailing water and temperature conditions, among other factors. Crop diversification can serve as insurance against rainfall variability as different crops are affected differently by climate events (Orindi and Eriksen 2005; Adger et al. 2003). The second strategy focuses on crop management practices geared toward ensuring that critical crop growth stages do not coincide with very harsh climatic conditions such as mid-season droughts. Crop management practices that can be used include modifying the length of the growing period and changing planting and harvesting dates (Orindi and Eriksen 2005).

From Table 4, it is clear that rise in temperatures followed by decrease in rainfall, prolonged dry spells in between rains, terminal heavy rains, and prevalence of pests and diseases (powdery mildew, mold in castor; smut and jassids in paddy) are the major farmers' perceptions in that order of magnitude regarding climate change in Mahbubnagar. It is striking to note that farmers across the world show a remarkable unanimity in observations of seasonal change, particularly regarding rain falling in most intense bursts, and generally higher temperatures and longer hot, dry spells within rainy seasons, with effects on soil moisture (Jennings and Magrath 2009). Kemausuor et al. (2011) reported that a large percentage (93 %) of farmers was of the opinion that the timing of the rains is now irregular and unpredictable.

As stated by farmers in Table 5, staggered sowings, change in planting dates, requiring of drought-resistant crops, and construction of water-harvesting structures are the major adaptation measures followed by farmers toward climate change in Mahbubnagar.

Table 5 Farmers' adaptation measures toward climate change in Mahbubnagar

S. no.	Farmers' adaptation measures	Number[a]	%	Rank
1.	Staggered sowings (dry paddy, castor, red gram, and cotton in kharif), (groundnut, paddy, chilies, and tobacco in rabi)	50	83	I
2.	Change in planting dates and planting different crops	49	82	II
3.	Requiring of drought-resistant varieties	45	75	III
4.	Construction of water-harvesting structures started under MGNREGA	41	68	IV

Table 6 Farmers' perceptions regarding climate change in East Godavari

S. no.	Farmers' perception	Number[a]	%	Rank
1.	Rise in temperatures	54	90	I
2.	Decrease in rainfall	53	88	II
3.	Pest and disease incidence is high for kharif paddy like BPH, BLB, and stem borer (at transplanting stage)	51	85	III
4.	Terminal heavy and unseasonal rains	49	82	IV
5.	ITKs for rain forecasts are failing	45	75	V

Also, the farmers in Mahbubnagar are used to observe the pattern of rainy season, and if it gets copious rains, they will continue farming. Otherwise, they migrate and work as construction labor at Gangavati, Hyderabad, and Bangalore. Higher temperatures and pest and disease attack on crops were the chief perceptions of farmers toward climate change, while planting different crops and water conservation were the main adaptation strategies of farmers in Ogbomosho Agricultural Zone of Oyo State in Nigeria (Ayanwuyi et al. 2010).

Table 6 points to rise in temperatures, followed by decrease in rainfall, incidence of pests and diseases, terminal heavy cyclonic rains, and ITKs for rain forecast failing as the major farmers' perceptions in that order of magnitude regarding climate change in East Godavari.

Table 7 indicates that early sowings, saltwater spray for harvested paddy stalks, strengthening of riverbanks and improved drainage, survey number wise insurance, and loans to tenant farmers are the major adaptation measures perceived by farmers toward climate change in East Godavari. Migration of construction labor if monsoon fails (June–September rains) in rainfed areas of the district is another common phenomenon (Ravi Shankar et al. 2013).

Since most smallholder farmers are operating under resource limitations, lack of credit facilities and other inputs compounds the limitations of resource availability, and the implications are that farmers fail to meet transaction costs necessary to acquire the adaptation measures they might want to and at times farmers cannot make beneficial use of the available information they might have (Kandlinkar and Risbey 2000). Lack of access to credit has been observed in previous studies (Nhemachena and Hassan 2007) to be a barrier to responding to climate change. Furthering adaptive capacity is in line with general sustainable development, and

Table 7 Farmers' adaptation measures toward climate change in East Godavari

S. no.	Farmers' adaptation measures	Number[a]	%	Rank
1.	Going for early (June) sowings to avoid November cyclones coinciding with harvests	56	93	I
2.	Saltwater spray for harvested paddy stalks to avoid discoloration and regermination. For paddy in field, tying with rope and sticks on four sides to keep them erect and not falling down	55	92	II
3.	Strengthening of riverbanks and improved drainage	53	88	III
4.	Survey number wise insurance covering low lands	50	83	IV
5.	Loans to tenant farmers, though introduced, fall short of actual requirements in terms of coverage	48	80	V

policies that help reduce pressure on resources reduce environmental risks and increase the welfare of the poorest members of the society.

A better understanding of how farmers perceive climate change, ongoing adaptation measures, and the factors influencing the decision to adapt farming practices is needed to craft policies and programs aimed at promoting successful adaptation of the agricultural sector (Bryan et al. 2009).

Computation of Adaptation Index to Assess the Extent of Farmers' Adaptation to Climate Change

Each farmer was scored for adaptation by assigning scores of 0, 1, and 2 for non-, partial, and full adaptation of a measure, respectively. In case of drought and floods, total adaptation measures were 8 for each, respectively, and hence maximum adaptation score that can be obtained is 16, while minimum adaptation score that can be obtained by a farmer is 0. Adaptation indices were computed by dividing adapted measures with total recommended measures and multiplied with 100 for assessing the extent of adaptation. Adaptation index is expressed in percentage (%).

The adaptation indices for the three districts along with their SD (standard deviation) and CV (coefficient of variation) values are presented in Table 8. Table 8 shows that the mean adaptation index value for floods (12.13) (East Godavari) is greater than that for droughts (11.90, 11.65) (Anantapur and Mahbubnagar, respectively).

Village-Wise and Practice-Wise Adaptation Scores of Farmers

Adaptation to climate change is the adjustment of a system to moderate the impacts of climate change to take advantage of new opportunities or to cope with consequences (Adger et al. 2003).

Table 8 Adaptation indices of farmers for drought and floods

Statistic/category	Anantapur (drought)	Mahbubnagar (drought)	East Godavari (floods)
Mean	11.90	11.65	12.13
SD	2.14	2.22	1.97
CV	17.96	19.02	16.23
Max.	15	15	16
Min.	6	6	6

Table 9 Village-wise adaptation scores of farmers for drought in Anantapur district of Andhra Pradesh (AP)

S. no.	Village	Minimum	Maximum	Mean	SD	CV
1.	*Bhadrampally*	6	15	12	3.2	26.4
2.	*Siddharamapuram*	6	15	11.1	2.5	22.3
3.	*Nagasamudram*	9	15	12	2	16.7
4.	*Chenne Kothapalli*	12	12	12	0	0
5.	*Podarallapalli*	12	15	**13.2**	1.5	11.7
6.	*Mangalamadaka*	9	15	11.1	2	18.2

Table 10 Village-wise adaptation scores of farmers for drought in Mahbubnagar district of AP

S. no.	Village	Minimum	Maximum	Mean	SD	CV
1.	*Machanpally*	9	15	**12.6**	1.9	15.1
2.	*Appaipally*	6	15	11.1	2.5	22.3
3.	*Nirven*	12	15	12.3	0.9	7.7
4.	*Palem*	6	15	11.7	2.6	22.5
5.	*Penchikalapadu*	6	12	9.9	2.8	28.7
6.	*Aragidda*	12	15	12.3	0.9	7.7

Table 11 Village-wise adaptation scores of farmers for floods in East Godavari district of AP

S. no.	Village	Minimum	Maximum	Mean	SD	CV
1.	*Gollaprolu*	12	16	**13.9**	1.7	12
2.	*Chendurthi*	9	15	11.7	2.2	18.9
3.	*J. Thimmapuram*	6	12	11.1	2	18.2
4.	*Kattamuru*	9	16	12.7	2.1	16.2
5.	*Narsapuram*	9	12	11.4	1.3	11.1
6.	*Dora Chintalapalem*	9	15	12	1.4	11.8

From Tables 9, 10, and 11, the villages, namely, *Podarallapalli* in Anantapur (13.2), *Machanpally* in Mahbubnagar (12.6), and *Gollaprolu* in East Godavari (13.9), showed highest mean adaptation values for droughts and floods, respectively.

The code and the adaptation practice it represents are given in Tables 12 and 13.

Table 12 Code and adaptation practices for drought in Anantapur and Mahbubnagar

Code	Adaptation practice
A1	Improved irrigation
A2	Minimized irrigation loss
A3	Construction of water-harvesting structures (WHS)
A4	Drought-resistant crops
A5	Timely supply of inputs
A6	Contingency crop planning
A7	Crop management by adjusting planting dates
A8	Soil management by mulching, conservation tillage

Table 13 Code and adaptation practices for floods in East Godavari

Code	Adaptation practice
A1	Water storage
A2	Strengthening of riverbanks
A3	Flood forecasting and early warning systems
A4	Drainage aspects
A5	Better soil and crop management practices
A6	Credit
A7	Insurance
A8	Community-based water management

Table 14 Practice-wise mean adaptation scores of farmers for drought in Anantapur district of AP

Statistic	A1	A2	A3	A4	A5	A6	A7	A8
Mean	1.12	1.0	**1.97**	**1.97**	0.85	1.20	**2.00**	**1.80**
SD	0.52	0.64	0.18	0.18	0.36	0.40	0.00	0.40
CV	46.90	63.78	9.20	9.20	42.36	33.61	0.00	22.41

From Table 14, practices A3 (construction of water-harvesting structures), A4 (drought-resistant crops), A7 (crop management by adjusting planting dates), and A8 (soil management by mulching, conservation tillage) showed highest adaptation in Anantapur. This amply illustrates the need for water harvesting, storage, and reuse.

From Table 15, practices A3 (construction of water-harvesting structures), A4 (drought-resistant crops), A7 (crop management by adjusting planting dates), and A8 (soil management by mulching, conservation tillage) showed highest adaptation in Mahbubnagar. This amply illustrates the need for water harvesting, storage, and reuse.

From Table 16, practices A3 (flood forecasting and early warning systems), A4 (drainage aspects), A5 (better soil and crop management practices), and A8 (community-based water management) showed highest adaptation in East Godavari. The problem here is managing excess water.

Table 15 Practice-wise mean adaptation scores of farmers for drought in Mahbubnagar district of AP

Statistic	A1	A2	A3	A4	A5	A6	A7	A8
Mean	1.05	0.97	**1.92**	**1.92**	0.83	1.13	**2.00**	**1.83**
SD	0.47	0.55	0.28	0.28	0.38	0.34	0.00	0.38
CV	44.45	57.03	14.54	14.54	45.10	30.25	0.00	20.50

Table 16 Practice-wise mean adaptation scores of farmers for floods in East Godavari district of AP

Statistic	A1	A2	A3	A4	A5	A6	A7	A8
Mean	1.02	1.18	**1.85**	**1.85**	**2.00**	1.20	1.20	**1.83**
SD	0.22	0.43	0.36	0.36	0.00	0.40	0.40	0.42
CV	22.12	36.46	19.46	19.46	0.00	33.61	33.61	22.83

Conclusion

Common perceptions of climate change across the three regions in AP are rise in temperatures, decrease in precipitation, and incidence of pests and diseases to crops. Adaptation measures practiced for drought are insurance, change in planting dates, working as migrant laborer, and construction of WHS. For floods, early sowings, saltwater spray for harvested paddy stalks, strengthening of riverbanks, and improved drainage are the chief adaptation measures. The mean adaptation index value for floods (East Godavari) is greater than that for droughts (Anantapur and Mahbubnagar). Practice A7 (crop management by adjusting planting dates) showed highest adaptation in Anantapur and Mahbubnagar. Practice A5 (better soil and crop management practices) showed highest adaptation in East Godavari.

Rise in temperatures is almost always echoed by farmers irrespective of season and place. Decreasing precipitation is yet another common concern, which usually when occurring in severe intensity bursts does an impression of pricking on human skin. Water conservation is the need of the hour, to avoid runoff of excess rainwater in a short period of time. Farmers believe that it has great potential in addressing the impacts of climate change. Incidence of pests and diseases on crops complement with varying humidity levels in the atmosphere deserves attention. Until now minor crop pests, be it on dry sorghum or castor and paddy, are becoming major is another important observation by farmers.

Adaptation/adjustments to climate change at household level by farmers which are carried single handedly through experience and observation require greater support in terms of continuance with or without slight modifications. Insurance, changing planting dates, and planting different crops in a staggered manner come under this household adaptation category. Construction of water-harvesting structures under MGNREGA in dry districts of the study is an encouraging sign and should be promoted wherever possible. Since crop management strategies are ad hoc and immediate, farmers show a great degree of preference to it to tide over the situation, for example, change in planting dates, intercrops, etc. However, in attaining greater resilience toward climate change, soil management concepts and practices should be instilled among farmers like conservation tillage, mulching, recycling of nutrients, etc. For floods, proper drainage system for the floodwaters to empty into the sea is lacking. Drainage systems often suffer from inadequate maintenance and need improvement works like desiltation, lining of the walls, and weed removal. There is need for imparting greater awareness, education, and training about climate change issues to farmers in supporting adaptation efforts. The challenge which remains for scientists is developing quick-maturing, drought- and lodging-resistant crop varieties to surmount the current and future climate change in agriculture.

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Climate Change and Agriculture in Dry Areas

Muhammad Saqib, Javaid Akhtar, Riaz H. Qureshi, and Ghulam Murtaza

Contents

Abstract

This chapter explores the implications of climate change for agriculture in dry areas in the context of decreasing quantity and diminishing quality of water. It proposes adaptation strategies for planning national and regional responses to climate change. This chapter analyzes the impacts of climate change on agriculture in dry areas taking into consideration different adaptation efforts underway and the bottlenecks faced. On the basis of this analysis, it presents certain guidelines for responses to climate change in dryland agriculture. The findings of this chapter include an elucidation of the impacts of climate change on agriculture in dry areas and the factors which contribute to these impacts. In addition

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certain adaptation guidelines are proposed. Agriculture is the most important sector of life affected by climate change. The findings of this chapter will be useful for all the stakeholders including policy makers, agricultural managers, and the farmers. Agriculture in general and in drylands in particular is vulnerable to climate change. However, the impacts of climate change on agriculture and the possible adaptations are not studied extensively. Therefore, the present chapter is expected to provide original information on the subject of climate change and agriculture in dry areas.

Keywords
Climate change • Agriculture • Dry areas • Environment • Mitigation • Adaptation

Introduction

According to the World Atlas of Desertification, the areas where the ratio of mean annual rainfall and mean annual potential evapotranspiration is between 0.05 and 0.20 are classified as arid areas, and the areas where this ratio is between 0.2 and 0.5 are classified as semiarid areas (UNEP 1992). About 41 % of the Earth's land surface is covered by drylands with a population of more than two billion people and more than 90 % of these are in the developing countries (IIED 2008). This makes the drylands home to about one-third of the global population. However, according to United Nations Development Programme (UNDP), the arid and semiarid regions occupy about 30 % of the total area of the world and are home to 1.10 billion people or around 20 % of the total world population. About 24 % of the total population of Africa, 17 % of the Americas and the Caribbean, 23 % of Asia, 6 % of Australia and Oceania, and 11 % of Europe live in the arid and semiarid areas (UNSO 1997). The major dryland areas of the world include West African Sahel and Dry Savannas, East and Southern Africa, North Africa and West Asia, Central Asia and the Caucasus, and South Asia.

Dry areas are home to most of the world's poor and many poorest of the poor who live on less than 1$ a day (White et al. 2002). The dry areas have high population growth with low employment rate and high number of youth population, rapid urbanization, poverty, social inequality, and poorly developed markets and institutes. The health, nutrition, and living conditions are very poor in the dry areas.

The drylands are very poor in renewable water supply (less than 8 % of the renewable water resources of the world) and have low and variable precipitation and very low organic matter (IIED 2008). Low water availability is the most important limiting factor for sustainable food production from drylands. The most water-scarce regions of the world are Middle East and North Africa. The problem of water scarcity is compounded with groundwater depletion. The dry areas are also home to the most vulnerable agricultural ecosystems which are hit hard by the climate change.

World food production is seriously affected by climate change particularly in the arid and semiarid regions. The productivity of dry areas is much less than their potential and the need of the people living in these areas. For example, wheat yields are up to 30 % lower in dry areas than the global average. Similarly, the livestock and poultry production is very low in the dry areas. This low productivity leads to food imports and price hikes which threatens the food security and livelihoods of the poor people of these areas. Drylands often witness famines and natural disasters which lead to resource damage and political unrest.

History shows that extremes of heat, cold, droughts, and floods have caused devastation to the agricultural systems in the dry areas. Climate change has added to susceptibility of these areas to poverty, hunger, famine, and dislodgment. It therefore needs time to develop strategies and policies to increase food production on sustainable basis in the drylands of the globe. The agricultural and pastoral systems in dry areas are very complex and include pastures, rangelands, forests, fish and livestock, and rainfed and irrigated production systems. The management and development of the dry areas require an approach that can integrate different cropping, pastoral, forest, and livestock systems.

Climate Change-Induced Problems of Dry Areas

Climate change is the change in the weather over a long period of time. Rising levels of greenhouse gases in the global atmosphere and increasing concentrations of aerosol particulates are considered to noticeably affect the world climate systems (Santer et al. 1996). These changes lead to a rise in the world mean temperature and sea level. The mean surface temperature of the world has increased by about 0.6 °C over the twentieth century (IPCC 2001). The data from the northern hemisphere showed that this rise in temperature during the twentieth century is the maximum during a century since 1000 A.D. According to IPCC (2013), over the period of 1880–2012, the global average temperature has increased by 0.85 (0.65–1.06) °C. Agriculture is very sensitive to climate change-induced long-term trends and short-term variability of rainfall and temperature and of the occurrence of droughts, floods, heat waves, frosts, and other extreme events (IPCC 2012). Climate change is increasing threats to food safety and post-harvest losses and danger from invasive species, pests, and diseases (Vermeulen et al. 2012). The incidence and geographic spread of diseases of the human beings, animals, and plants is also likely to increase in a warming climate. Climate change particularly challenges the sustainability of food production systems and the natural resources in the areas of widespread or intense water stress and environments prone to degradation and desertification and where the poor people cannot take the needed preventive steps (IPCC 2012). Almost all the global circulation models predict that the dry areas will be hit hard by the climate change. The agroecosystems of dry areas are challenged with drought, floods, salinity, extreme temperatures, biodiversity loss, and land degradation. The farmers of the dry areas often have smallholdings and practice a mixed

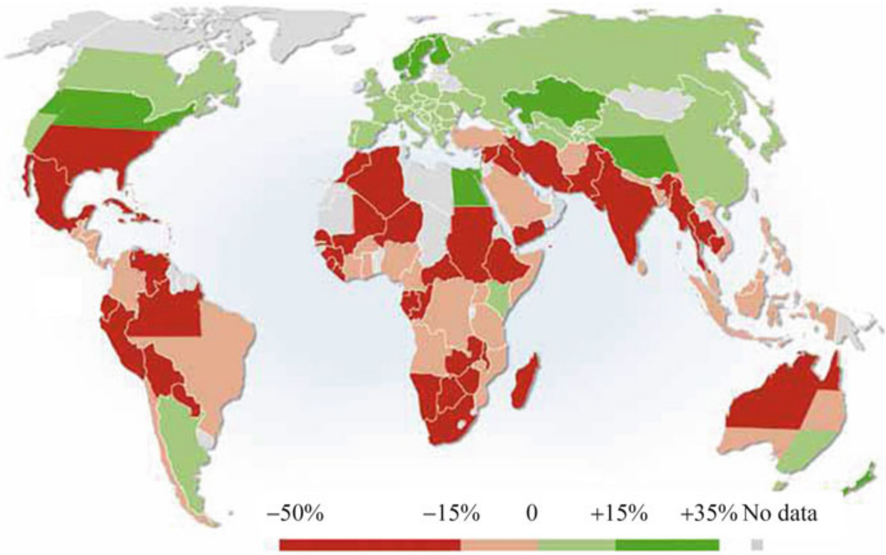

Fig. 1 **Projected changes in agricultural production in 2080 due to climate change**. Projections assume a uniform 15 % increase in yields due to the fertilization effect of rising carbon dioxide in the atmosphere on some plant species (Note that this coarse-grain analysis does not project local-scale impacts which require geographically specific analysis) (Cline 2007)

farming system comprising of rainfed cropping and livestock. These activities are mostly vulnerable to climate change that results in loss of biological potential and desertification of these areas. Climate change results in demographic changes in the agricultural areas. People migrate from one place to the other along with their livestock and enhance the load on water and soil resources of an already stressed area. This leads to poor resource management and conflicts between the nomads and the farmers of a particular area.

The food security, life quality, poverty, agriculture, and climate change are strongly linked with agriculture playing a key role in the linkage. Climate change is intensifying the problems of drylands, and the situation is predicted to get worse with time, and the drylands will have to rely more and more on the unreliable food imports. Agriculture in drylands is highly vulnerable to climate change (Fig. 1). The crop and livestock yields in the dry areas are reduced or crop failure occurs due to unreliable precipitation pattern. The overall rainfall levels have declined with climate change, and the drought events have become frequent and more intense. A change in global temperature is causing a shift in the climatic zones. The length of growing seasons is decreasing, and the pests and diseases are increasing and spreading in the areas where they were not prevalent in the past. New pests and diseases are also emerging under these conditions. A decrease in food production in the dry areas has occurred under the changing climatic conditions, and the situation is expected to get worse. This lowers the farm income, spikes the commodity prices, and increases the import of food commodities. These developments as a result of climate change are going to affect the sociopolitical stability of already geopolitically volatile dryland countries.

Climate Change Adaptation and Mitigation Strategies for Agriculture in Dry Areas

Agriculture, food security, and environmental resilience in dry areas essentially need widespread adoption of sustainable agricultural practices. The global burden of hunger is bound to increase as the frequency of extreme weather events like droughts and floods is predicted to increase (Beddington et al. 2012). Therefore, future global agriculture needs to produce more food for the growing population while adapting to changing climate (Foresight 2011; Lobell et al. 2011).

Agriculture can enhance as well as decrease the climate change and its impacts. Greenhouse gas emissions from agriculture include emissions from ruminant digestion (sheep, goat, and cattle), rice fields, and fuel use. Methane, nitrous oxide, and carbon dioxide emitted by livestock activities (i.e., enteric fermentation and manure management) and land-use changes make a substantial contribution to anthropogenic greenhouse gas emissions (Steinfeld et al. 2006). Deforestation for land clearing for agriculture also significantly contributes to greenhouse emissions (Smith et al. 2007). These greenhouse gas emissions enhance climate change. On the other hand, agriculture provides a major sink of carbon in vegetation and soil that contributes to adaptation and mitigation of climate change. Therefore, better and improved agricultural activities can reduce risk and may create a win-win situation for agriculture in dry areas. These activities may include better resource management, genetic improvement, and socioeconomic institutional support for these areas (Anonymous 2012, 2013). This section describes these activities for sustainable dryland agriculture systems.

Prioritization of Resource Utilization

Land and water resources are under tremendous pressure in dry areas and need to be used very wisely and judicially. Producing more with little is the major challenge for agriculture in the dry areas. To meet this challenge, it is very important to prioritize the resource utilization on high potential lands and marginal lands. The high potential lands and marginal lands need different strategies to maximize returns from these lands. There are drylands with good production potential, relatively friendly environmental conditions, better access to markets, and institutional support. These areas should be targeted for intensive food production using high-yielding, resource-efficient, and stress-resistant crop varieties and livestock breeds. There are the dry areas with poor/marginal land and water resources with poor access to markets and poor institutions. The major focus in these areas should be to reduce their vulnerability to climate change and avoid resource degradation. Therefore, the aim here is to decrease risk and vulnerability of these rural communities and to increase their resilience to climate change. These areas may support only very hardy plants and animal species. Rearing goats and sheep is a good option in these areas as different fodder species are hard enough to be grown in these areas. Awassi sheep is a good example as it supports the livelihood of many people in the dry areas of Middle East through providing milk, meat, and wool. This may also be used in other dryland areas.

Diversification and Integration of Crop-Livestock Systems

Land and environment suitability of crops and livestock should be extensively studied and explored. Diversification of crops, livestock species, vegetables, and trees is needed in the dry areas. A shift from high water-using crops and animals to low water-using crops and animals should also be encouraged. The diversification of agricultural systems can mitigate risk and improve income in dryland areas. Introduction of innovative uses of the arable land resources, introduction of new plants, and value addition to the existing food production in the existing agricultural systems can improve economic returns and mitigate risks.

Genetic Improvement of Crop and Livestock

Genetic improvement of crops and livestock is a key toward sustainable agriculture and food security in the dry areas. This can improve the efficiency and resilience of the food production systems in the dry areas under changing climatic conditions. The breeding programs need to be more site specific toward the environmental conditions, pests and diseases at a particular area. The genotypes developed for a particular situation may be more resource efficient under these conditions. The "Gokce," a drought-tolerant variety of chickpea introduced in Turkey, is a good example (Anonymous 2012). Biotechnology is applied in the development of varieties with superior traits including resilience to climate change and low input requirements. Some crops have been genetically engineered to reduce GHG emissions from agriculture and therefore contribute to climate change mitigation. Genetic improvement in the livestock sector also helps the farmers to adapt to climate change and reduce greenhouse gas emissions. Crops and livestock with low greenhouse gas production should be selected and promoted.

Seed has become a very costly input in agriculture. Therefore, seed development and seed-keeping are very important for a better harvest. The farmers of the dry areas may be trained in seed-keeping to reduce crop raising costs and increase farm income. The women of the Matigsalog tribe in Davao City, Philippines, were trained for selection of suitable rice varieties for different conditions which helped them to select and preserve right seeds and improved their resilience to climate change-induced problems in rice production (APEC 2012).

Conservation Agriculture

Conservation agriculture and site-specific management have found to be suitable for farming in the dry areas. Conservation agriculture involves reduced soil disturbance, retaining crop residues and conserving water and crop nutrients. It follows zero till or no-till system of cultivation. It reduces costs and improves soil health, nutrient cycling, and crop yields. It increases carbon sequestration and decreases greenhouse gas emission from agricultural land and contributes to climate change mitigation. Efficient input utilization in agriculture minimizes input use and carbon emission. Fertilizer application may be reduced by nutrient recycling through the decomposition of plant residues. When used with other improved crop management practices, conservation agriculture has given good results for wheat, barley, chickpea, and lentil. A change in animal feed, improvement in animal housing, and better waste and manure management in livestock can reduce CH_4 emissions. Alternative agricultural practices, suitable for a particular region, can reduce the emission of greenhouse gases and hence will help to maintain or improve yields and to adapt to extreme weather events (Pretty et al. 2011). However, the farmers are reluctant to follow conservation agriculture at many places as it may involve initial costs and the initial benefits are gained after some time. The policy makers are also afraid that not as much food can be produced from conservation agriculture as from the conventional ways. Similarly, limited availability of resources is a hindrance toward changing to a more conservative approach (FAO 2006).

Water Conservation and Management

Water is the most important but limited and endangered entity in dry areas. It is the single most important factor controlling the sustainability of dryland agriculture systems and dryland communities. Therefore, efforts at all levels are needed to increase its utilization efficiency. Improved water use efficiency is also needed to reduce fresh water use in agriculture which is up to 90 % in some countries. Water resources management is complicated as the key physical water bodies like rivers, lakes, and watersheds cut across the political borders. These water resources and their management provide the basis of agricultural development in dry areas. The related problems like flooding, drought, and rise in sea level also go across the political boundaries. Therefore, a cost-efficient and environment-friendly water management requires integration at farm, ecosystem, and policy levels. A successful integrated water resources management requires "top-down" as well as "bottom-up" approach including policy, funding, and institutional support and farm-level activities. Irrigation systems giving high water use efficiencies should be introduced in the dry area.

Agricultural Research, Education, and Extension

Climate change adaptation and mitigation and sustainable food production from the dry areas need modernization of agriculture. Introduction of new technologies has improved wheat yields of the dryland farmers by 22 % in Egypt and 58 % in Sudan. Agricultural adaptation to climate change is very costly and needs to be supported financially from different climate change adaptation funds. Climate smart initiatives and climate smart technologies can be helpful in sustaining and increasing food production and protecting the natural resources of the dry areas. The improved adaptation and mitigation measures will not only improve food security but will also reduce the agriculture-induced climate change by reducing greenhouse gas emissions from agriculture.

International and National Policies and Agreements

There is a strong need to increase human capacity to benefit from current and future trade-offs and to capitalize on synergies between food security and climate change adaptation and mitigation options. A strong leadership is needed at international institutes and policy processes for this purpose. It is the dire need of the dryland countries that agriculture and food security should get an important place in the discussions in the global bodies including the United Nations Framework Convention on Climate Change (UNFCCC), the Group of 20 nations (G20), and the United Nations Convention on Sustainable Development (the organizing body of the Rio + 20 Earth Summit). These bodies should be persuaded to adopt appropriate actions including policy and financial measures to improve implementation of sustainable solutions to climate change in drylands on a global level. All the dryland countries essentially need agriculture-friendly policies in this era of climate change. COP-17 in Durban has been good as the agriculture has been specifically mentioned for the first time in the text of UNFCCC. Long-term investment and funding is needed to finance the new technologies. Climate change adaptation and mitigation are costly, and a considerable funding from international agencies is required, if the dryland communities are to be sustained and further developed. A number of technologies are available today to overcome the problems of the drylands; however, these need to be taken to the field through financing, training, and advocacy to the governments as well as to the farmers.

Climate change will continue to challenge the livelihoods of the people of dryland areas. These areas are difficult to manage but need more attention of the policy makers and donors as these areas have received less investment in the past. In the twenty-first century, agricultural development is important for achieving food security and adaptation to and mitigation of climate change. Agriculture is a key sector for climate change resilience particularly in the drylands as it is accepted that climate change will severely affect the development and life in the rural areas. A concentration on the dry areas is very important for improving food security, nutrition and health, conservation of natural resources, and decreasing social inequality.

Dryland Development Beyond 2015: Beijing Statement

Dryland Development Beyond 2015: Beijing Statement of the 11th International Drylands Development Conference of the International Dryland Development Commission (18–21 March, 2013, Beijing, China) summarizes the issues, options, and solutions related to the drylands (ICDD 2013). The statement narrates as:

> Drylands – comprising deserts, rangelands, rainfed croplands, wastelands, and some savanna woodlands – cover about 41 % of Earth's land surface and are inhabited by more than 2 billion people. More than 50 % of the poor and malnourished of the world live in the dry areas and suffer from food insecurity, and socio-economic and socio-political instability. Many of these areas face severe land degradation, potentially undermining the productivity of these important ecosystems. Natural and semi-natural ecosystems are being degraded by the mismanagement of water resources, inappropriate land use practices and overgrazing. Increasing fuel prices are making agricultural inputs and operations more costly, reducing agricultural productivity, and increasing food prices. The impact of global climate change would worsen the situation. Therefore, there is **an urgent need to pay attention to improving coping capacity of the people in the dry areas and minimizing vulnerability by** developing knowledge-based adaptation and mitigation modalities through global cooperation. Hence, it is imperative that the **post-2015 development agenda** by the international community takes account of the challenges faced by over 2 billion people living in these drylands. Consolidated responses must undertake drylands development in a manner that adequately addresses water, food, feed, and energy security concerns and offer opportunities for economic development while respecting the rich and varied social and cultural heritages.
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> The **Participants of the Conference**, representing research and development community from **29 countries** and **14 regional and international organizations**, have come to the conclusion that this can be achieved in two ways:
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> **First**, the sustainable development goals (SDGs) should maintain a sharp focus on issues that are of relevance to drylands: reducing poverty through sustainable land management, protecting livelihoods and ensuring human wellbeing, adequate management of scarce water resources, and providing incentives to governments for initiating proactive responses to land degradation. The notion of green economy may provide us a useful starting point for formulating such SDGs. In this new paradigm of sustainability, the notions of carbon footprint and water footprint must figure centrally within green economy policies. However, this must be balanced to become globally equitable.
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> **Second**, countries and people must be resourced to meet with new and emerging challenges, the awareness of which has to be enhanced amongst all stakeholders. As climate change exposes us to unprecedented water stress and impacts on biodiversity, no region is more adversely impacted than drylands – and we must therefore work on building societal resilience against such new challenges. This can be achieved by: (a) developing scientific and technological resources and making them available to governments and other stakeholders in drylands developing countries; (b) mobilizing and further developing human and institutional capacity in developing countries, ensuring gender equity and empowerment, particularly around sustainable land, water and genetic resource management, adopting an agro-ecosystem approach; (c) mobilizing new capital, both in the public and private sectors, to develop institutions and infrastructure and sustainable renewable energy sources; and (d) introducing specific enabling policies and legislation.

Conclusions

Climate change is a reality and no more a speculation. The occurrence of extreme weather events has become a routine around the globe particularly in the dryland regions. Drylands are home to a significant human population who has no other option except to earn their livelihoods from these vulnerable areas. They are already living in the poorest living conditions which are faced with increasing challenges and problems with time. Agriculture is the only sector which can ensure the sustainability, food security, and improvement of life quality of dryland communities. Therefore, agricultural research should emphasize to develop new resource-efficient genetic materials and technologies which can tolerate the extreme climatic events under dryland conditions. It is not possible without financial and policy support from national and international institutions, governing bodies, and commissions.

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Climate Change and Water Issues in Mesopotamia: A Framework for Fostering Transboundary Cooperation in Euphrates-Tigris Basin

Vakur Sümer

Contents

Abstract

This chapter starts with presenting an overview of the current situation in Mesopotamia in terms of both water resources and increasing impacts of climate change over water resources. The existing literature on potential problems of climate change in Euphrates-Tigris region will also be discussed. Then the chapter turns to the question of how countries of the region may come together around the theme of water and increase their adaptive capacities in the face of climate-related threats.

Keywords

Mesopotamia • Euphrates • Tigris • Iraq • Syria • Turkey • Climate change • Water resources • Macro-region

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Introduction

The two significant rivers in the Middle East, Euphrates and Tigris (ET), characterize the area which was historically known as Mesopotamia. The Mesopotamia region constitutes a single basin ending in the Persian Gulf. The area witnessed the earliest urban civilization in Sumerian times and is called as the "Cradle of Civilization." It also historically is part of the greater "Fertile Crescent" stretching from the Nile Delta through Jordan River and through Euphrates-Tigris into the Persian Gulf. Food production in the region continues to be vital not only for the population living in the basin but for the entire populations of the riparians. The water-dependent area of Mesopotamia now faces with the threats of climate change which could turn out to be disastrous if adaptation strategies are not implemented in timely manner.

There is a growing literature on the possible impacts of climate change on Mesopotamia.[1] However, little has been done in order to improve the adaptive capacity in the face of climate change in the region. Moreover, despite this recent literature, there is a lack of reliable historical data which renders it difficult to develop robust models of changes in time (Rifai 2008; Voss et al. 2013). Adaptation to climate change, certainly, entails a wide range of issues (Moser and Dilling 2004). One significant part of climate change adaptation is to develop the transboundary cooperation since the basin is shared by a number of countries, and as it is already known, climate change knows no boundaries.

Within this framework, this chapter aims to present a model for transboundary cooperation, particularly with regard to transboundary water resources in the region. Building upon a recent EU model and taking water as a common ground for action, this chapter tries to propose a coherent and holistic perspective for an ever climate-adaptive Mesopotamia. The chapter starts with presenting an overview of the current situation in Mesopotamia in terms of both water resources and increasing impacts of climate change over water resources. The existing literature on potential problems of climate change in Euphrates-Tigris region will also be discussed. Then the chapter turns to the question of how countries of the region may come together around the theme of water and increase their adaptive capacities in the face of climate-related threats.

Climate Change Impacts on Water Resources in Mesopotamia

Euphrates and Tigris are two significant rivers in the southwest Asia. They are important not only because of their length which makes them "transboundary" rivers but also because of their water volume which makes the region of

[1]See, for instance, Voss et al. (2013), Yilmaz and Imteaz (2011), Topcu et al. (2010), Sowers et al. (2011), Kitoh et al. (2008).

Mesopotamia as one of the most fertile agricultural regions in the world as well as their potential in terms of hydroelectricity.

Euphrates is the longest river of the region (approx. 2,700 km). The Kara Su and the Murat are two main tributaries of Euphrates in the headwaters. These two tributaries, along with the Balikh and Khabur tributaries which join Euphrates downstream, drain the heavy winter/spring precipitation in the form of runoff from the southeastern Taurus Mountains. The Tigris River, the second longest river in southwest Asia (1,840 km), originates in eastern Turkey near Lake Hazar and flows southeast where it forms the border with Syria for approximately 40 km and then enters into Iraq. Several tributaries contribute to the Tigris including the Greater Zab, the Lesser Zab, the Adhaim, and the Diyala. The Tigris and Euphrates converge near the Iraqi city of Qurna and continue as the Shatt al Arab, and finally, they drain into the Persian Gulf (Kolars and Mitchell 1991).

There are three major riparians of the Euphrates-Tigris River basin: Turkey, Syria, and Iraq.[2] Euphrates annual mean flow is 32 billion cubic meters per year (bcm/year). Ninety percent of the mean annual flow of the Euphrates originates from Turkey, and the 10 % originates from Syria. Tigris, on the other hand, has 52 bcm/year of annual average flow. While 40 % of the total discharge originates from Turkey, 51 % originates from Iraq and 9 % from Iran (Kibaroglu) (Fig. 1).

There was not a serious water issue in the region – at least in the political arena – until the second half of the twentieth century. Until then rivers were utilized by the populations living nearby. The water question emerged as a significant political – as well as a societal – issue when the three riparians initiated major water development projects in 1960s. The main reason for this was the decreasing sufficiency of water resources of the basin for the local communities in the basin and, more importantly, the need for supplying water and energy (hydroelectricity) for the rapidly increasing populations of urban agglomerations whether close by or distant from the source (Elhance 1999). Therefore, the rapid demographic changes in Mesopotamia could be seen as one of the reasons for making water resources more critical.

The increase in Turkey's population could be a good example. The total population of Turkey was 13.5 million in 1927. It increased to 31.2 million by 1965. This means a 2.5-fold increase in less than 40 years. Syria's and Iraq's populations demonstrate similar trends during these times.

And despite the decreasing rates of population increase in Turkey, Syria and Iraq continued to increase at higher percentages.[3] Iraq's population, for instance, grew from 6 to 32 million in the last six decades. Syria's population, likewise, grew from 3.5 to 22.5 million during the last 60 years. Aymenn Jawad Al-Tamimi and Oskar Svadkovsky summarize the official population policy in Syria in the last 60 years:

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[2]It should be noted, however, that some territories of Iran and Saudi Arabia belong to the ET basin geographically and that Iran contbitutes 5–8 % of the river flow of Tigris.

[3]Note that the population of Turkey increased less than four times of its 1950 number, while Syria grew more than six times, and Iraq grew nearly six times during the last six decades.

Fig. 1 Map of Mesopotamia (Source: Heston et al. (2012))

> The seeds of the current disaster were planted as far back as 1956, when Youssef Helbaoui – head of economic analysis in Syria's Planning Department – famously declared: "A birth control policy has no reason for being in this country. Malthus could not find any followers among us." Since then Syria has been living in a state of one uninterrupted demographic cataclysm. The regime was so obsessively pro-natalist that in the early 1970s, the trade and use of contraceptives in Syria were officially banned. By 1975, the birth rate reached 50 live births per 1,000 people, with Hafez al-Assad asserting that a "high population growth rate and internal migration" were responsible for stimulating "proper socio-economic improvements" within the development framework.
>
> Even when other nations in the Middle East began to take measures to curb their population growth as the danger of demographic collapse started to loom over the region, the regime in Syria was struggling to make up its mind on the issue." (Al-Tamimi and Svadkovsky 2012)

Now, there are more than 100 million additional people living in these three basin countries when compared with 1950 numbers. This huge increase in the basin countries' population largely remained dependent to water resources of Euphrates and Tigris and, when taken in conjunction with climate change-induced decreasing levels of available water in the rivers, resulted in a water crisis, which is still surmounting (see Figs. 2, 3, and 4).

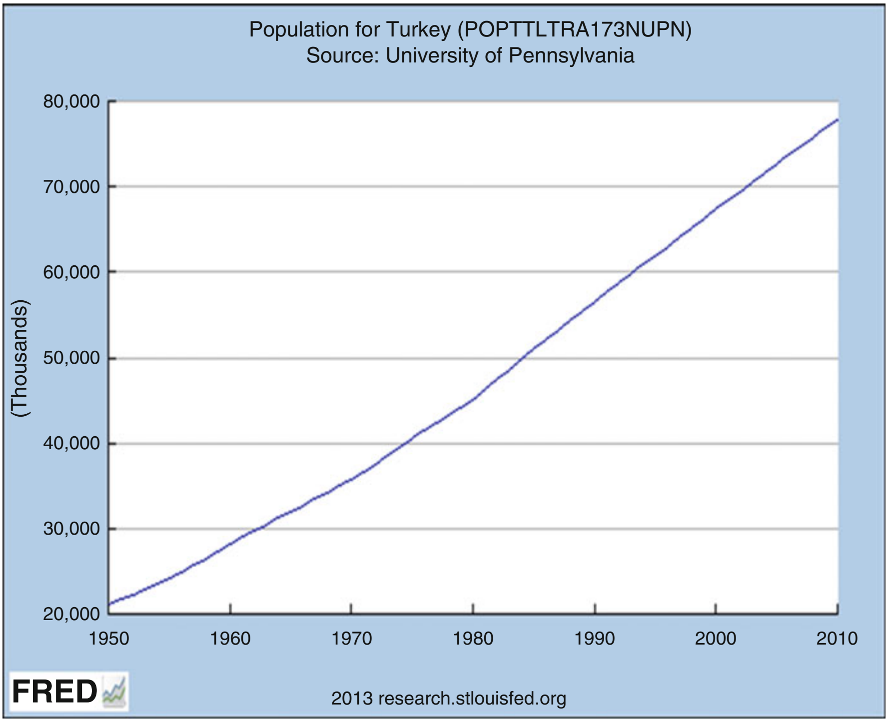

Fig. 2 Population of Turkey (Source: Heston et al. (2012))

Combinations of these push factors with a pull factor, i.e., the advent of new construction technologies enabling huge dams to be built which characterized the “hydraulic mission”[4] era, resulted in huge infrastructure plannings throughout the region countries (see Table 1). In other words, countries of the region hitherto dealt with these decreasing levels of per capita water with supply-side measures. They constructed a considerable number of reservoirs in order to continue to supply water for irrigation during dry seasons. Among these, Southeastern Anatolia Project (Turkish acronym GAP) of Turkey appears to be the biggest water-related infrastructure project undertaken in the basin.[5] Construction of additional water supplies did contribute to the water management in the basin in several aspects. Built reservoirs provide water supply guarantee throughout the year. They also appeared

[4]Hydraulic mission is a concept within a modernist world view, meaning “the strong conviction that every drop of water flowing to the ocean is a waste and that the state should develop hydraulic infrastructure to capture as much water as possible for human uses” (Wester et al. (2009). The hydraulic mission and the Mexican hydrocracy: Regulating and reforming the flows of water and power. Water Alternatives 2(3): 395–415).

[5]GAP consisted of 22 big dams and 19 hydropower plants in Turkish parts of Euphrates and Tigris basin.

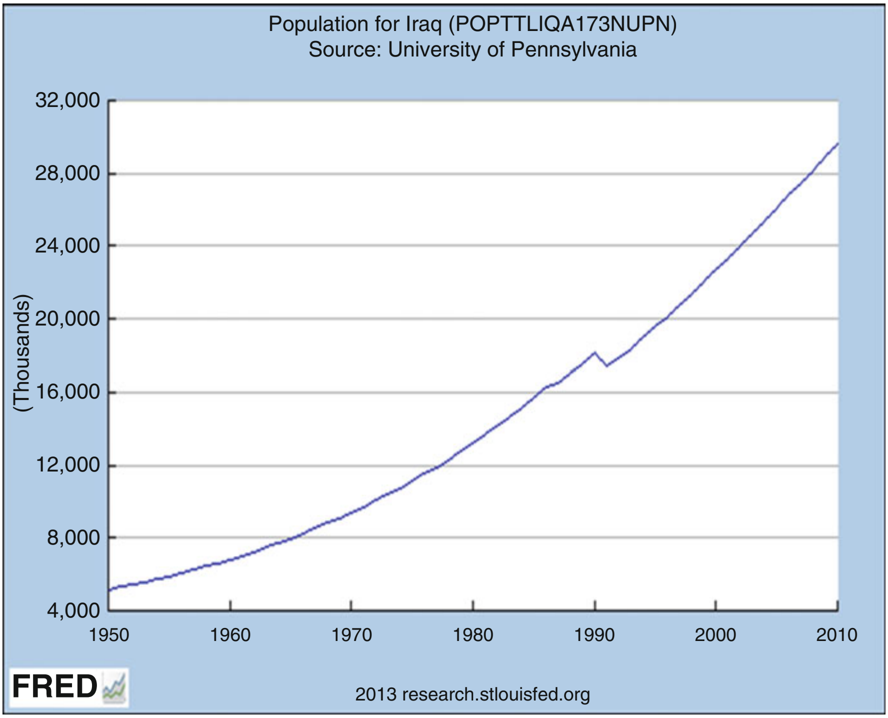

Fig. 3 Population of Iraq (Source: Heston et al. (2012))

to be useful when recurring floods are considered. Since they regulated the water flow, floods became unusual events. However, despite these contributions, huge reservoirs in the basin bear a number of potential harms, particularly in the face of climate change. For instance, huge surface area of these man-made lakes (or canals) has a problem of evaporation. Evaporation losses amount to be huge in shallow water bodies in downstream like Thartar canal in Iraq. Therefore, countries in the region might need to focus also on better management of reservoirs in the basin. If countries could agree, in accordance with the topographic and climatic imperatives, reserving much of the water in upstream could be a solution.

Thus, since the 1960s, not only Turkey and Syria began developing the potential of Euphrates-Tigris River system for basically energy production and irrigation, but also Iraq initiated new schemes for irrigation. The culmination of all these unaligned efforts was an increased water imbalance in the region and, not to mention, a patchwork approach to climate change-related threats. As FAO noted, it is clear that water resources in the semiarid or arid zones like the Middle East are already stressed, independent of climate change, and any additional stress from climate change or increased variability will only intensify the competition for water resources. The Middle East, being the world’s most water-stressed region, climate change – which is projected to cause sea-level rise, more extreme weather events

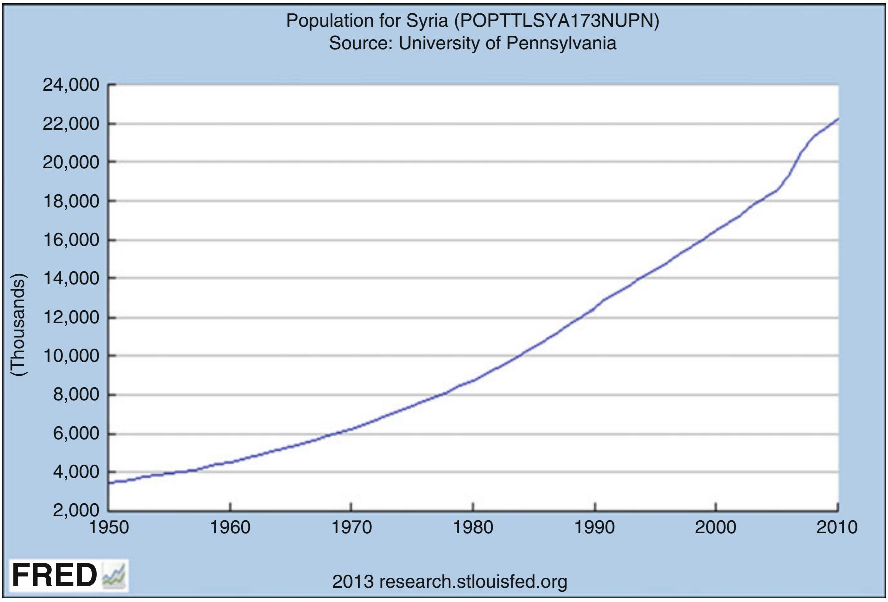

Fig. 4 Population of Syria (Source: Heston et al. (2012))

such as droughts and floods, and less precipitation – will contribute to even greater water stress in the region (Freimuth et al. 2007). Within this context, "future vulnerability depends not only on climate change but also on development plans, so that appropriate strategies followed for sustainable development can reduce vulnerability to climate change" (Topcu et al. 2010).

To date, most governments in the wider Middle East have concentrated largely on large-scale supply-side measure including desalination, dam construction, interbasin water transfers, tapping fossil groundwater aquifers, and importing virtual water. According to Sowers et al. (2011), societal involvement is one of the keys in a successful climate adaption strategy, where it lacks in the Middle East region. Sowers et al. (2011) conclude that "the key capacities for adaptive governance to water scarcity in MENA remains to be underdeveloped." What is more, all intended solutions remain to be uncoordinated and single-country solutions, lacking the transboundary dimension which needs to be taken seriously for a working climate adaptation strategy.

Climate Change and Increasing Pressures on Water Resources

The Mediterranean basin and its surrounding area, which includes Mesopotamia, are regarded as among the most climate-vulnerable regions in the world. Climate change is already underway in the ET region. The increasing impacts of climate change in the Euphrates-Tigris region have been experienced by a number of indications.

Table 1 Dams in the Tigris–Euphrates watershed

Name	Completion	Use[a]	Country	Basin	Max. vol (10^9 m^3)[b]	Prin. vol (10^9 m^3)[c]	Max. SA (km^2)[d]	Prin. SA[e]	Res. K[f]
Dokan	1961	IRR	Iraq	Tigris	6.8	4.6	270	200	1
Derbendikhan	1962	IRR	Iraq	Tigris	3	2	121	78	1
Keban	1975	HP	Turkey	Euphrates	31	21.6	675	458	2.5
Tabaqa	1975	HP	Syria	Euphrates	11.7	9.6	610	447	2.5
Hamrin	1980	IRR	Iraq	Tigris	3.95	2.15	440	195	2.5
Mosul	1985	HP, IRR	Iraq	Tigris	11.1	8	371	285	2.5
Haditha	1984	HP, IRR	Iraq	Euphrates	8.2	7	500	415	4
Karakaya	1987	HP	Turkey	Euphrates	9.6	7.1	268	198	1
Ataturk	1992	HP, IRR	Turkey	Euphrates	48.7	38.7	817	707	2
Kralkizi	1997	HP	Turkey	Tigris	1.9	1.1	57.5	39.2	2
Batman	1998	HP, IRR	Turkey	Tigris	1.175	0.745	49.3	37.3	2
Tishreen	1999	HP	Syria	Euphrates	1.9	1.8	166	142	2

Source: Jones et al. (2008)
[a]*IRR* irrigation, *HP* hydroelectric power
[b]Maximum volume in billion cubic meters
[c]Principal volume in billion cubic meters
[d]Maximum surface area in km^2
[e]Principal surface area in km^2
[f]Reservoir hydraulic conductivity in mm/h

Voss et al. (2013) analyzed the changes in overall freshwater storage in the Euphrates-Tigris basin from January 2003 to December 2009. Their study indicated alarming rate of decrease in total water storage of approximately -27.2 ± 0.6 mm yr^{-1} equivalent water height, equal to a volume of 143.6 km^3 during the course of the study period. The Euphrates also has been widely reported to have become very narrow and shallow.[6] Indeed, a decreasing trend in lower Euphrates streamflows based on historical flow data analysis has already been demonstrated (Yilmaz and Imteaz 2011, p. 1277). Moreover, despite the decrease in overall precipitation, flood intensity and frequency have a tendency to rise (IPCC 2007).

Shifts in rain patterns have led to prolonged droughts all around the Middle East in recent years. As pointed out by Shetty (2006), for instance, "dramatic changes in climatic and hydrologic features in recent years have affected the economies of the region and specifically those of the dry areas where rainfed agriculture is the dominant activity and the only source of income for a majority of the rural population." The drought in Iraq in 2008, a case in point, was one of the harshest ones in the country's history which forced the country to enter into new negotiations which then culminated in signing of a memorandum of understanding in September 2009. Climate change-induced impact was particularly devastating in Syria, as al-Tamimi and Svadkovsky (2012) note, "agriculture remains a major part of the economy and the lifestyle of a large section of the population, some 20 % of Syria's GDP being generated by this sector." It was reported that "aggravation of water scarcity led to the abandonment of around 160 villages in northern Syria in the period 2007–2008. In eastern Syria, the Inezi tribe saw some 85 % of its livestock killed between 2005 and 2010 because of prolonged drought. In 2010 the United Nations estimated that more than a million people have left the northeast of the country" (Al-Tamimi and Svadkovsky 2012).

Apart from these experienced changes, recent scientific studies also warn about the expected magnitude and threats of future climate change. Therefore, the recent trends of climate change seem to continue in the upcoming years and decades. In a widely cited paper, Chenoweth et al. (2011), on the other hand, found that the average annual Euphrates-Tigris River discharge could decline by 9.5 % by 2040–2069 with the greatest decline (12 %) in Turkey.[7]

Another study suggests that climate change has the potential to severely reduce (between 10 % and 60 %) the amount of this water source and place increased stress on the water-dependent societies of the region[8]. The decrease in the Euphrates

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[6]Faisal Rifai, Impact of Collaboration in the Euphrates Tigris Region, http://www.inbo-news.org/IMG/pdf/rifai.pdf

[7]It should be noted at this point that both Euphrates and Tigris are largely snow-fed rivers which are dependent on winter precipitation, particularly in Turkey. The Taurus Mountains and the Anatolian Highlands of eastern Turkey are the headwater regions for the Tigris and Euphrates Rivers, whose waters are shared primarily between Turkey and, downstream riparians, Syria and Iraq. In other words, the runoff from the Taurus Mountains of Turkey supplies water to 2/3 of the Arabic-speaking population of the Middle East (Cullen and deMenocal 2000).

[8]Ozdogan (2011).

basin, in particular, appears to be more alarming: "Discharge of the Euphrates River is projected to decrease between 29–73 percent by the end of the 21st century" (Kitoh et al. 2008; Granit and Joyce 2012).

Dai (2011), reviewing recent literature on drought of the last millennium, concludes that most of the Middle East will experience an increased aridity in the twenty-first century. In light of the above, although there is a remarkable variance in study findings, nearly all of studies agree on the prospect that there will be less water in the Euphrates-Tigris basin in the future. Bozkurt and Şen provide a synopsis of what could be expected in the twenty-first century in the Euphrates basin which is worth quoting:

> Temperature: All scenario simulations indicate surface temperature increases across the entire Euphrates-Tigris bsin. Projected increase in annual surface temperature in the highlands ranges between 2.1 °C and 4.1 °C for 2041–2070, and between 2.6 °C and 6.1 °C for 2071–2099.
>
> Precipitation: Projected precipitation decrease in the highlands by the end of the present century in 33 % under the higher emissions scenario (A1F1) and 6–24 % under the A2 scenario. Snow water equivalent precipitation in the highlands is projected to decrease by 55 % for B1 scenario, 77–85 % for A2 scenario and 87 % for A1F1 scenario.
>
> River discharge: The territory of Turkey will likely experience more adverse direct effects of the climate change compared to the territories of the other countries in the basin. The annual surface runoff is projected to decrease by 26–57 % in the territory of Turkey by the end of the present century. (Bozkurt and Şen)

Then, the question, is not whether or how the climate will change in Mesopotamia, but the questions that experts and decision-makers should be dealing with are, first, what these adaptive strategies are and, perhaps more importantly, how these adaptive strategies that are necessary for mitigating climate change could be implemented in the region as a whole, because climate change is such a phenomenon that renders national or regional boundaries obsolete and that necessitates a holistic approach, including spatial integration among other "integrations." In other words, in order to succeed in designing and implementing basin-wide measures aiming a successful climate adaptation, we need to transcend national boundaries and integrate the climate-vulnerable zones of the region into a unified whole. Within this context, a successful climate adaptation strategy necessarily means a transboundary cooperation.

A number of measures are hitherto taken from the supply-side thinking. One key element of adaptation is diversification of water management strategies; another is ensuring equitable access for vulnerable populations. Most MENA countries already employ a variety of supply-side measures, including dams, water transfer schemes, desalination, reuse of treated wastewater, and procuring "virtual water" (Allan 2001) through imports. Water experts in the region, in concert with international institutions, increasingly advocate demand management to promote conservation and increase efficiency.

Any cooperation attempt in the Euphrates-Tigris basin should aim at improving the water use in agriculture, because the greatest consumer of water, by far, in the Middle East is irrigation/agriculture. On average, more than 70 % of water in the region is used in agriculture. As pointed out by Shetty (2006), countries in the region now face with "increasing pressure to allocate water away from agricultural to industrial and municipal uses, as well as to increase water efficiency within the agricultural sector."

On the other hand, rapid population increases put the region in a difficult dilemma. Improving agricultural water use appears to be difficult with the continuing trends of population increases in the basin. Recent climatic models for eastern Mediterranean and Turkey predict a significant reduction in precipitation (Gao and Giorgi 2008) that would require additional water withdrawals from the Tigris and Euphrates Rivers to meet agricultural demand throughout the basin. This "could have devastating effects on the water availability" in the whole basin. As Voss et al. (2013) conclude, "the decline in agricultural output significantly influences economic stability in the region and will continue to be a threat owing to perennial limitations on water availability and the emerging threats of climate change, including more prolonged drought." Thus, whereas better climate mitigation requires water savings particularly in agriculture (this means countries of the region must focus their efforts in reallocating water towards nonagricultural water uses and use water more efficiently in agriculture[9]), this is not straightforward because of the fact that water is an indispensable element in food production in these countries and also farmers comprise big constituencies in all three countries.

One possible way out of this deadlock seems to be utilization of "virtual water," which is already in place to some extent. Both Iraq and Syria are increasingly importing foods. This is partly because of the recent warlike situation in these countries. In other words, if opportunity appears, these countries will opt for growing their own food instead. Therefore, there is a limit for virtual water: "food security." Countries of the region do not want to rely on foods from international market.

Adaptation to Climate Change in Mesopotamia Through Transboundary Water Cooperation

Steps necessary for climate adaptation need a holistic perspective in terms of national or regional boundaries. Therefore, intrastate solutions may not yield optimum outcomes when the question is about a phenomenon that does not know borders (Solomon et al. 2007). However, it appears to be quite difficult to realize a "transboundary" approach to climate change-related threats, particularly since it is mostly interconnected with the sensitive issue of water.

A number of studies have long focused on methods of how to foster the cooperation in the Euphrates-Tigris region.[10] Nevertheless, given a number of

[9]This strategy is also known as "more crop per every drop."

[10]For discussions on ET cooperation, inter alia, see Asit Biswas (ed.), *International waters of the Middle East from Euphrates-Tigris to Nile*, Oxford University Press, Oxford, 1994; Ayşegül Kibaroğlu, *Building a regime for the waters of the Euphrates-Tigris river system*. Kluwer Law International, London, The Hague, New York; Naff and Matson, *Water in the Middle East: Conflict or Cooperation*. Westview Press, Boulder, 1984; Scheumann W, Schiffler M (eds) *Water in the Middle East: potential for conflicts and prospects for cooperation*. Springer, Berlin; Gün Kut Burning Waters: Hydropolitics of the Euphrates and the Tigris. In New Perspectives on Turkey, (9) (Fall), 1993.

factors limiting the construction of trust among countries, a workable solution for cooperation in this region of the world could not be easily implemented. Any attempt towards cooperation needs to take into account of the past experiences and long-lasting clashes of views and try not to cause additional problems instead of resolving them. In the past, several concepts and proposals were found "hegemonic" or "biased" and did not find ways of implementation.[11] Therefore, there is the need for a neutral approach which would not create antagonisms. The "macro-region strategy" could be treated such an unbiased concept.

Instead of facing the multifaceted and complex "water sharing" problem bluntly and as a single case for solution, the macro-region concept proposes an "issue-based" and "project-oriented" cooperation with an aim of making cooperation a habit in the region through working together around the priorities of all. Deconstructing the bigger problem of "lack of water cooperation" into smaller projects for attainable goals could work better. Within this context, climate change-related threats could be more easily dealt with.

Box 1. The EU Model of Macro-Region: Lessons from Neighborhood (Excerpts from INTERACT 2009)

Definition of macro-region: "an area including territory from a number of different countries or regions associated with one or more common features or challenges."

"An area covering a number of administrative regions but with sufficient issues in common to justify a single strategic approach."

"Its borders are not delimited once and for all, but their 'extent depends on the topic: for example, on economic issues it would involve all the countries in the region, on water quality issues it would involve the whole catchment area'. The macro-region is thus presented as a *functional* region, sharing challenges, opportunities and solutions.

The antecedents of the EU's currently-promoted macro-regional conceptualization can be traced back to the Brussels European Council of 14 December 2007, with the Council's 'invitation to the Commission to present an EU strategy for the Baltic Sea Region'.

"Macro-regional strategy requires no new ad hoc legislation. The main content is the preparation and implementation of a Plan of Action that derives from a strategic paper mostly drafted by national governments and the European Commission through a consultative approach. It is an endogenous 'bottom up' process: contrary to policies that descend from a communitarian strategic approach, the macro-region establishes its strategy through the involvement of local actors. Furthermore, the Plan of Action is *concrete* and contains tangible effects thanks to the identification of *flagship projects*."

(continued)

[11] See Warner (2008).

> "In all cases, the principle will be to add value to interventions, whether by the EU, national or regional authorities or the third or private sectors, in a way that significantly strengthens the functioning of the macro-region. Moreover, by resolving issues in a relatively small group of countries and regions the way may be cleared for better cohesion at the level of the Union."
>
> "Working together can become a habit and a skill. In addition, overall coordination of actions across policy areas will very likely result in better results than individual initiatives."
>
> "Concreteness: The one indispensable element in a macro-regional strategy is the resulting action. Strategies that consist of words in documents, and nothing more, will not achieve their objectives. An action plan, or something comparable, is therefore the sine qua non of an effective strategy. However, an action plan that stands alone risks being little more than a wish list. There is a need for an organising approach that explains and justifies the selection, prioritisation and sequencing of selected actions."

Risks and Opportunities for the Mesopotamia

EU's functional model of macro-regions (Dubois et al. 2009; Stocchiero 2010) is a relatively novel approach which needs to be carefully studied and adapted to the conditions of the Middle East. When the Euphrates-Tigris basin is concerned, there are a number of certain risks and opportunities associated with this proposed scheme. It could be summarized as follows:

Opportunities:

(a) New and neutral concept (it is easier to build trust in the region with an unbiased concept).
(b) Possible EU support and possible UN support (as well as other donors may contribute funding for establishing a secretariat, educational aid, training aid for relevant personnel).
(c) The issue of water is common to many problems of all three countries of the region (gathering around common conflicts).
(d) Establishment of a governing commission could be a starting point for further cooperation.
(e) There are a clear model (EU) and a clear timetable to follow.

Challenges:

(a) Lack of political will for such a framework of action (two countries of the region, Iraq and Syria, are presumably in flux, and water cooperation has not been given due attention).

(b) Lack of accountability and the problem of democratic deficit.
(c) Capacity (technical, personnel) and funding is problematic in war-torn countries of Syria and Iraq.
(d) There is no EU Commission-like body for acting as a guardian of the agreed projects.

Building upon the opportunities and challenges listed above, the third stage would be composed of drawing up a "roadmap" for initializing and sustaining the cooperative framework of macro-region. One of the most significant parts of this roadmap would be the discussion of different scenarios of the institutional setup. For instance, creating a working commission (like the one in the EU) would be conducive to cooperation, but it could be easily abused and become a way of limiting the cooperation. Therefore, the institutional design of the new cooperative scheme should be meticulously analyzed with its far-reaching implications.

In the fourth stage, designation of a number of flagship projects will be designed. These will be the beacons of cooperation for particularly the initial phases of the macro-region strategy. Anchoring in these flagship projects would have a likelihood to create a path-dependent attitude towards cooperation.

The success of such a cooperative action framework will largely depend on the level of political commitment of the countries concerned rather than the foreign support. Therefore, the bulk of the needed investments are to be covered by the countries of the region, which renders this project difficult since both Iraq and Syria would not like to initiate and financially contribute to this framework. And Turkey, on the other hand, has not much to gain with this cooperative scheme given its dominant position in terms of geographic position (upstream) and water resources utilization.

Conclusions

This chapter aims to analyze water-related implications of climate change in Euphrates-Tigris (ET) transboundary river basin and create a framework for advancing the international level of cooperation in order to better deal with common challenges that countries of the region began to face. The chapter began with a discussion of the possible undesirable water-related implications of climate change in ET basin countries (namely, Iraq, Syria, and Turkey) through utilization of existing scientific literature, then presents the current level of cooperation among three riparians and the gap between these challenges and existing transboundary water cooperation, and finally proposes a framework and an action plan for deepening water-based cooperation in the basin in order to tackle with the climate change-related challenges.

Reports originating from the Intergovernmental Panel on Climate Change (IPCC) conclude that freshwater systems are among the most vulnerable to climate change. In snow-dominated basins (such as the ET), hydrologic studies have long agreed that warming will result in earlier peak flows, greater winter flows, and lower summer flows. Also, climate models suggest that warmer temperatures will very likely lead to greater climate variability and an increase in the risk of extreme hydrologic events such as floods and droughts. The existing level of cooperation among three riparians does not allow for successful management of the impacts of climate change, because there is hitherto no multilateral and comprehensive agreement involving all three riparians and all water-relevant issues.

The chapter attempts to provide a detailed framework for addressing the water-related risks of climate change in ET basin and discuss the applicability and effectiveness of possible solutions. Climate change-related impacts of desertification and water scarcity which could worsen the prevailing poverty in vast areas of the region necessitate systematic action by all countries of the region. In order to open up underexplored venues for target-oriented cooperation, the neutral concept of "macro-region" – which would be a project-driven process (Bialasiewicz et al. 2012; Medeiros 2011) – has been presented. Successful implementation of flagship projects in priority areas would become a basic trust-building measure for strengthening the development of a common understanding for regional problems, which appears to be one of the prerequisites for mitigating climate change-related problems.

According to various scenarios, the climate change will be one of the most challenging phenomena in the Middle East, including the ET basin. Common challenges of this magnitude could only be dealt with collaborative action. To this end, this chapter proposed a neutral concept not only for advancing the practical cooperation among basin countries in the face of climate change but for also promoting the trust between three countries, which appears to be one of the prerequisites for strengthening cooperative ties. The chapter adopted a novel approach and focused on issue-based and attainable targets and project-driven solutions for lessening the adverse impacts of climate change in the region.

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Climate Change and Water Security in Dry Areas

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Abstract

Water quality is deteriorating and its availability is decreasing with time. This chapter presents the implications of climate change for water in agriculture and environment in dry areas. Further adaptation strategies for sustainable use of water resources under changing climatic conditions is proposed.

This chapter analyzes the impacts of climate change on water availability and its quality. It considers the ongoing adaptation efforts and the problems faced in implementing these strategies. Certain guidelines and recommendations for addressing climate change in the water sector are also proposed.

This chapter elucidates the impacts of climate change on water quality and availability. Factors that govern these impacts are highlighted and certain adaptation guidelines are proposed.

Water is a nonrenewable resource directly affected by climate change. All stakeholders, including policy makers, water managers, and water users will benefit from this chapter.

Climate change has significant impact on water quality and availability. However, not many studies have been devoted to exploring the impacts of climate change and the possible measures to mitigate these impacts on water resources. Thus, the management of original and valuable work on the subject is presented.

Keywords

Climate change • Water security • Dry areas • Environment • Mitigation • Adaptation

The Climate System and the Hydrological Cycle

The cryosphere (snow, ice, and frozen ground) on land stores about 75 % of the world's freshwater. In the climate system, the ice cover and its changes are intricately linked to the surface energy budget, the water cycle, and sea level change. More than one-sixth of the world's population lives in glacier or snowmelt-fed river basins (Stern 2007). Satellite data show that there have been decreases of about 10 % in the extent of snow cover since the late 1960s (Rangwala and Miller 2012).

The water reservoir such as ice caps, glaciers, and permanent snow are among the most sensitive indicators of climate change (Seiz and Foppa 2007), advancing when climate cools (e.g., during the Little Ice Age) and retreating when climate warms. Glaciers grow and shrink, both contributing to natural variability and amplifying externally forced changes. There are 5.773×10^6 cubic miles of water in ice caps, glaciers, and permanent snow. According to the National Snow and Ice Data Center, if all glaciers melt today, the seas would raise $\approx$ 230 ft. Luckily, that is not going to happen all in one go, but sea levels will rise. Initially, based mainly on aerial photographs and maps, this compilation has resulted in a detailed inventory of more than 100,000 glaciers covering a total area of 2.4×10^5 km^2. In preliminary estimates, based on the records, the remaining ice cover was estimated to be $\approx 4.45 \times 10^5$ km^2. The World Glacier Monitoring Service collects data annually on glacier retreat and mass balance. Mass balance data indicate 17 consecutive years of negative glacier mass balance.

Retreating mountain glaciers cover 680 km^2 of the earth surface, that is, 4 % of the total surface area of land covered by ice on earth. Mountain glaciers make 1 % of land ice; however, 99 % of mountain glaciers have been retreating since the mid-nineteenth century. The changes in sea level, snow cover, ice extent, and rainfall are consistent with warming climate near the earth surface.

The appearance of ice on lake, river, and sea surfaces requires prolonged periods with air temperatures below 0 °C. High air temperatures and warmer winds will affect the duration of ice cover, the freezing and thawing times, and the thickness of ice cover. Climatic conditions not only influence the timing and duration of the ice cover but also the thickness of the ice cover and the nature of breakup (Beltaos and Prowse 2009).

Driven by solar energy, the climate system is complex and interactive, comprising of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things (Parry 2007). The climate system evolves over time under the influence of its own internal dynamics and due to changes in external factors that affect climate. External factors include natural phenomena (e.g., volcanic eruptions, solar variations, etc.) as well as anthropogenic activities that alter atmospheric composition and land cover and land-use change. Alterations in any of these factors can modify the balance between incoming short-wave sun radiation and outgoing long-wave radiation. The climate system responds both directly and indirectly to such changes.

The hydrological cycle designates a continuous movement of water through oceans, atmosphere, and land surface. Powered by solar radiation, the hydrological cycle begins with the evaporation of water from the surface of the ocean, transported around the globe, and returns to the surface as precipitation (rain, snow, sleet, hail, etc.). Once water reaches the ground, one of two processes may occur: (i) water evaporates or transpires back into the atmosphere or (ii) water penetrates the surface and becomes groundwater. Groundwater seeps into oceans, rivers, and streams. The balance of water that remains on the earth's surface is runoff, which empties into lakes, rivers, and streams and is carried back to the oceans, where the cycle begins again (Várallyay 2010). Any variability in climate affects the hydrological cycle on earth which directly affects the water resources.

Climatic Change and its Drivers

Factors that can shape climate are often called climate forcing. These include such processes as variations in solar radiation, deviations in earth orbit, mountain-building, as well as continental drift and changes in concentrations of greenhouse gases. These are a variety of climate change feedbacks that can either amplify or diminish the initial forcing. Some parts of the climate system, like oceans and ice caps, react slowly to climate forcing because of their large mass. Therefore, the climate system can take centuries or longer to fully respond to new external forcing.

Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. Climate change is caused by factors that include oceanic processes (such as oceanic circulation), biotic processes, variations in solar radiation received by the earth, plate tectonics and volcanic eruptions, and human-induced alterations of the biosphere equilibrium; these latter effects are currently causing global warming, and "climate change" is often used to describe human-specific impacts.

Globally, the 1990s was the warmest decade and 1998 the warmest year in the instrumental record since 1861. New analyses of proxy data for the Northern Hemisphere indicate that an increase in temperature in the twentieth century is likely to have been the largest of any century during the past 1,000 years. Because fewer data are available, less is known about annual averages prior to 1,000 years.

On an average between 1950 and 1993, nighttime daily minimum air temperatures over land increased by about 0.2 °C per decade. This is twice the rate of increase in daytime daily maximum air temperatures (0.1 °C per decade). This has lengthened the freeze-free season in many mid- and high-latitude regions. The increase in sea-surface temperature over this period was about half that of the mean land surface air temperature. Arctic sea ice has decreased since 1973, when satellite measurements began. Since the start of the satellite record in 1979, both satellite and weather balloon measurements show that the global average temperature of the lowest 8 km of the atmosphere has changed by +0.10 °C $\pm$ 0.05 per decade, but the global average surface temperature has increased by +0.15 $\pm$ 0.05 °C per decade. The record shows a great deal of variability, for example, most of the warming occurred during the twentieth century, during two periods, 1910–1945 and 1976–2000.

The Earth may have warmed by an average of more than 1.7 °C over the past 150 years according to an analysis of the University of Wisconsin study of the freeze and thaw records for lakes and rivers in the Northern Hemisphere. Researchers found that the annual freeze of 26 bodies of water in North America, Asia, and Europe shifted later by about 8.7 days over the last one and a half century, while the spring ice breakup came about 9.8 days earlier. The study reported very strong evidence of a general warming from 1845 to 1995 in areas where there is ice cover. The change in the ice-on and ice-off days found in the study corresponds to an air temperature warming of about 1.8 °C over the past 150 years.

However, over the last century, a decrease of nearly 10 % snow cover and a 10–15 % decrease in spring and summer sea ice in the Northern Hemisphere have been witnessed. Other changes linked to climate include longer growing seasons, increases in rainfall and rainfall intensity in the Northern Hemisphere, and shifts when ice freezes and breaks up on rivers and lakes. The IPCC has projected that global average surface temperatures could increase by 1.4–5.8 °C by 2100. Daily minimum temperatures as well as the number of hot days, with less cold and frosty days will increase (Parry 2007).

The primary driver of climate change impacts on water resources is temperature. Current climate models suggest that effects of temperature increases are felt throughout the climatic regime leading to hydrological changes (e.g., seasonal redistribution and duration of rainfall) and other related impacts. These hydrological changes are manifested as periods of increased rainfall or floods as well as periods of drought. In addition to precipitation effects, increased temperatures are impacting glacier and snowmelt patterns, while also creating more extreme hurricane or typhoon conditions with associated high winds.

The global average precipitation and evaporation are also expected to increase by about 1–9 %. The precipitation changes are expected to vary from region to region, with increases over the northern mid- to high latitudes and in Antarctica during the winter. The intensity of extreme weather events is also likely to increase with greater extremes of both flooding and drought. Precipitation, temperature, and carbon dioxide levels can affect the demand for water as well as the supply.

Relationship and Degree of Elasticity Between Climate Change and Water Resources

Water resources are important to both the society and the ecosystems. The biology depends on a reliable supply of clean drinking water to sustain the health. We also need water for agriculture, energy production, navigation, recreation, and manufacturing. Many of these uses put pressure on water resources, stresses that are likely to be exacerbated by climate change. So, as temperatures rise, people and animals need more water to maintain their health and thrive. Many important economic activities, like producing energy, raising livestock, and growing food crops, also require water. The amount of water available for these activities may be decreased as the Earth warms and if the competition for water resources increases.

In many areas, climate change could increase water demands while shrinking water supplies. This shifting balance would challenge water managers to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, ranchers, energy producers, and manufacturers. In some areas, water shortages will be less of a problem than increases in runoff, flooding, or sea level rise. These effects can deteriorate the quality of water and can damage the infrastructure that is used to transport and deliver water.

Hydrological Variables

The water cycle is a delicate balance of precipitation, evaporation, and all of the steps in between. Warmer temperatures promote evaporation of water into the atmosphere, thus increasing the atmosphere capacity to "hold" water. Increased evaporation may dry out some areas and cause excess precipitation on other areas.

Climate warming observed over the past several decades is consistently associated with changes in a number of components of the hydrological cycle and hydrological systems such as changing precipitation patterns, intensity and extremes, widespread melting of snow and ice, increasing atmospheric water vapor, increasing evaporation, and changes in soil moisture and runoff. There is significant natural variability on interannual to decadal timescales – in all the components of hydrological cycle, often masking long-term trends. There is still substantial uncertainty in trends of hydrological variables because of large regional differences and because of limitations in the spatial and temporal coverage of monitoring networks (Huntington 2006).

The hydrology of arid and semiarid areas is particularly sensitive to climate variations. Relatively small changes in temperature and rainfall in these areas could result in large changes in runoff, increasing the likelihood and severity of droughts and/or floods.

Precipitation

Here the word precipitation includes rainfall, snowfall, dews, etc. There is a direct influence of climate change and global warming on precipitation. Increased temperature leads to greater evaporation and thus surface drying, thereby increasing the intensity and duration of drought as well as precipitation elsewhere. However, the water-holding capacity of air increases by about 7 % per 1 °C warming, which leads to increased water vapor in the atmosphere. Hence, storms (individual thunderstorms, extratropical rain or snowstorms, tropical cyclones) supplied with increased moisture could produce more intense precipitation events. Such events are observed widely occurring, even where total precipitation is decreasing. This increases the risk of flooding. The atmospheric and surface energy budget plays a critical role in the hydrological cycle and also in the slower rate of change that occurs in total precipitation than total column water vapor. With modest changes in winds, patterns of precipitation do not change much but result in dry areas becoming drier (generally throughout the subtropics) and wet areas becoming wetter, especially in the mid- to high latitudes: the "rich get richer and the poor get poorer."

This pattern is simulated by climate models and is projected to continue into the future. With warming, more precipitation occurs as rain instead of snow, and snow melts earlier; there is increased runoff and risk of flooding in early spring but increased risk of drought in summer, especially over continental areas. However, with more precipitation per unit of upward motion in the atmosphere, the atmospheric circulation weakens that results monsoons to falter. In the tropics and subtropics, precipitation patterns are dominated by shifts as sea-surface temperatures change (El Niño is a good example).

Although the precipitation has increased by 0.5–1 % per decade during the twentieth century, over most mid- and high latitudes of the Northern Hemisphere continents, and the rainfall has increased by 0.2–0.3 % per decade over the tropical (10°N to 10°S) land areas, rainfall has decreased over much of the Northern Hemisphere subtropical (10°N to 30°N) land areas during the twentieth century by about 0.3 % per decade (this is the region in which most of Pakistan is situated) (Imtiaz 2002; Rangwala and Miller 2012).

Most models simulate precipitation that occurs prematurely and too often and with insufficient intensity, resulting in recycling that is too large and a lifetime of moisture in the atmosphere that is too short, which affects runoff and soil moisture (Trenberth et al. 2007).

Evapotranspiration

There are very limited direct measurements of actual evapotranspiration over global land areas (Fig. 1). Decreasing trends during recent decades are found in sparse records of pan evaporation (measured evaporation from an open water surface in a pan, a proxy for potential evapotranspiration) over the entire globe. Using observations of precipitation, temperature, cloudiness-based surface solar radiation, and a comprehensive land surface model, Qian et al. (2006) found that global land evapotranspiration closely follows variations in land precipitation. Changes in evapotranspiration depend not only on moisture supply but also on energy availability and surface wind. Other factors affecting actual evapotranspiration include the direct effects of atmospheric CO_2 enrichment on plant physiology.

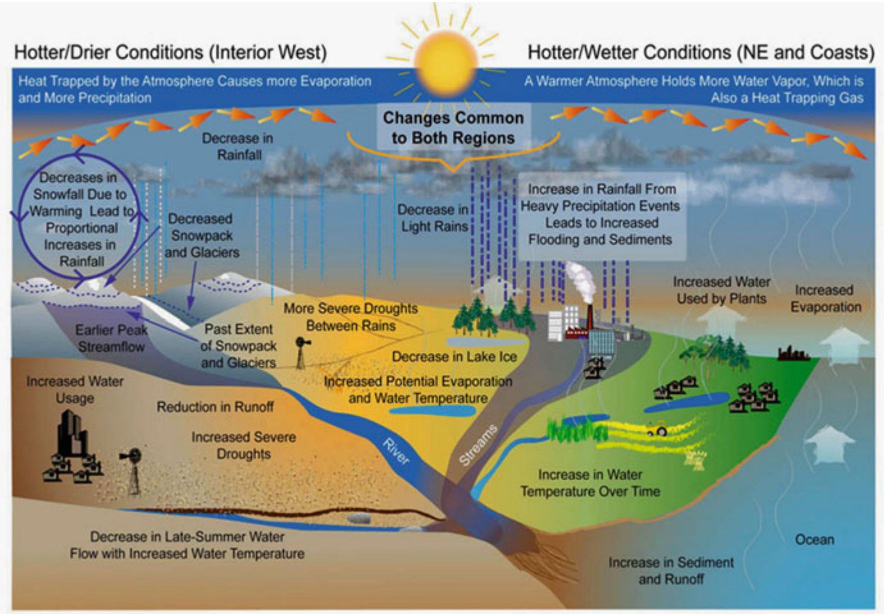

Fig. 1 Projected impacts of climate change on the hydrological cycle (Source: Karl et al. 2009)

Evaporative demand or "potential evaporation" is projected to increase almost everywhere. This is because the water-holding capacity of the atmosphere increases with higher temperatures, but relative humidity is not projected to change markedly. Resultantly, water vapor deficit in the atmosphere increases as does the evaporation rate (Trenberth et al. 2003).

Runoff

With an increase in precipitation (rain, snow, dew, etc.) and more snow melts earlier, there is increased runoff and risk of flooding in early spring with increased risk of drought in summer in dry areas. Climate change could cause more and intense precipitation but sporadic which is likely to be offset by the increased evaporative demand in many regions of South Asia and the world, i.e., where intense rainfall events with high runoff are interspersed with long dry periods of increased evaporation and transpiration.

Soil Moisture

Soil moisture is a source of thermal inertia due to its heat capacity and the latent heat required for evaporation. Soil moisture has been proposed as an important control on summer temperature and precipitation. Surface water balances reflect the availability of both water and energy. In regions where water availability is high, evapotranspiration is controlled by properties of both the atmospheric boundary layer and surface vegetation cover. Changes in the surface water balance can feed back on the climate system by recycling water into the boundary layer (instead of allowing it to run off or penetrate to deep soil levels). Changes in soil moisture depend on alterations in volume and timing not only of precipitation but also of evaporation which indirectly is affected by vegetation. The sign and magnitude of such effects are often highly variable depending on the details of the local environment (Bates et al. 2008).

Impacts of Climate Change on Surface Water Resources: Water Quantity and Availability

Excessive water uses put pressure on water resources, stresses that are likely to be exacerbated by climate change. In many areas particularly dry areas, climate change is likely to increase water demand while shrinking water supplies. This shifting balance would challenge water managers to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, ranchers, energy producers, and manufacturers. Climate change impacts on surface water (quantity and availability) vary greatly as discussed in the following sections.

Floods

Floods depend on a number of non-climatic factors like existence of dams or dikes. However, there are indications that climate change impacts their intensity and frequency. These flood-producing processes include intense and/or long-lasting precipitation, snowmelt, dam break, and decreased conveyance due to ice jams or landslides or by storm. Floods depend on precipitation intensity, volume, timing, phase (rain or snow), antecedent conditions of rivers, and their drainage basins (e.g., presence of snow and ice, soil characters, wetness, rate and timing of snow/ice melt, urbanization, existence of dikes, dams, and reservoirs). Human encroachment into recent and subrecent flood plains and lack of flood response plans increase their damage potential.

Globally, the number of great inland flood catastrophes during 1996–2005 is twice as large per decade as between 1950 and 1980. Based on climate models, the area flooded in Bangladesh is projected to increase by at least 23–29 % with a global temperature rise of 2 °C (Bates et al. 2008). This has been associated with an increasing frequency of heavy precipitation events; no ubiquitous increase is visible in trends in high river flows. With increased intensity and irregularity of rainfall, the interannular variability of river flows is likely to increase, such that rivers will become increasingly "flashy" and seasonal. As a result, flood events will be more common, and an increased proportion of the available surface water will lost in peak discharges, decreasing the quantity of accessible water (Parry 2007).

Drought

Drought is a normal, recurrent climatic feature which has caused distress since the known history of mankind. The term drought may refer to a meteorological drought, hydrological drought (low river flows and low water levels in rivers, lakes, and groundwater), agricultural drought (low soil moisture), and environmental drought (a combination of the above). The socioeconomic impacts of droughts may arise from the interaction between natural conditions and human factors such as changes in land use, land cover, and the demand for and use of water. Excessive water withdrawals can exacerbate the impact of drought.

Droughts have become more common, especially in the tropics and subtropics, since the 1970s. Pakistan has been suffering serious droughts periodically due to below normal rainfall. Although drought affects nearly all the climatic regimes and has pronounced consequences in both developed and developing countries, its effects are noticeably devastating in developing nations like Pakistan where rain-fed farming covers considerable area. Assessing the onset of drought, extent, intensity, and duration can limit drought-induced impacts and can provide a base to develop an effective drought mitigation response. Previous drought events in dry areas and the magnitude of drought losses indicate the continuing vulnerability of dry areas to drought due to lack of contingency planning. The integration of existing drought monitoring tools for dry areas is essential to decrease the vulnerability of drought in these regions. In order to reduce vulnerability to drought event in Pakistan, it is inevitable to assess relevant effects and identify their potential reasons. Due to spatial and temporal variability, it is imperative to enhance the data availability for mapping and monitoring this phenomenon. Drought-related multidisciplinary information can be handled by using geographic information system (GIS). Government institutions look after potential drought-stricken victims and others living in potential drought areas by using spatial analysis in GIS that can lead to a decision support system (Anjum et al. 2012).

Surface Water Runoff and River Discharge

The most dominant climatic drivers for runoff and river discharge are precipitation, temperature, and evaporative demand (Parry 2007). More precipitation brought about by more intense but sporadic rainfall events is likely to be offset by the increased evaporative demand in many regions of South Asia and the world, particularly where intense rainfall events with high runoff are interspersed with long dry periods of increased evapotranspiration. These conditions may lead to a greater risk of drying, land degradation, low groundwater recharge, and a significant decrease in the amount of available surface water, which are already seasonal (Meehl et al. 2007). Changes in river flows as well as lake and wetland levels will also depend crucially on whether precipitation as snow or rain. By the end of this century, rivers in South Asia are likely to exhibit decreased summer flows (after an initial increase) and increased winter flows resulting from recession of the Himalayan ice mass in a warmer condition. Glacial melt water presently contributes up to 70 % of the dry season flow of the Indus, so glacial recession will have significant impacts on water availability in South Asia climate (Kundzewicz et al. 2007).

At the global scale, there is evidence of a broadly coherent pattern of change in annual runoff, with some regions experiencing an increase in runoff and others experiencing a decrease in runoff.

Sea Level Rise

Global mean sea level is rising and the rate of rise has increased between the mid-nineteenth and the mid-twentieth centuries. The sea level increased about 18 cm (7 in.) during the past century. The most recent IPCC results suggest sea level might rise another 15–95 cm (6–37 in.) by the year 2100 owing to rise in temperature by 0.06 °C in the Atlantic, Pacific, and Indian Oceans (Parry 2007).

High sea levels and increased storm surges could adversely affect freshwater supplies to coastal areas. Saltwater in river mouths and deltas would advance inland and coastal aquifers and could induce threat of saltwater intrusion, jeopardizing the quality water for many domestic, industrial, and agricultural users. As the sea rises, saltwater will also move into freshwater areas. In addition, as more freshwater is removed from rivers for human use, saltwater will move farther upstream. Drought can cause coastal water resources to become more saline as freshwater supplies from rivers are decreased. Water infrastructure in coastal cities, including sewer systems and wastewater treatment facilities, faces risks from rising sea levels and the damaging impacts of storm surges.

Wildfire

Wildfire is a primary disturbance agent affecting the structure and composition of many forest ecosystems and hydrological cycle. The complex role that wildfire plays in shaping forests has been described in terms of vegetation responses as dependent on, sensitive to, independent of, or influenced by fire (Myers 2006). For example, fire is largely absent where cold, wet, or moist conditions prevail (e.g., tundra, some rain forests, and desert). At the other extreme, fire is essential where species have evolved to withstand burning and facilitate fire spread. Notable fire-dependent ecosystems include many coniferous boreal, temperate and tropical forests, eucalyptus forests, grasslands, savannas and marshes, and palm forests.

The specific weather conditions during a fire event greatly influence how the fire burns. It follows that long-term climate variability can influence fire behavior by affecting site-specific fuel conditions (fuel moisture, type and arrangement, and water availability). The fires we see today in some forest landscapes are of a much higher intensity than those at the turn of the twentieth century due to decades of fire suppression, an increase in biomass due to the post-1976 increase in southwestern rainfall (Swetnam et al. 1999) and warming temperatures coupled with intermittent drought conditions.

Climate change that results in drier, warmer climates has the potential to increase fire occurrence and may be affected due to the greenhouse effect. It is shown that future wildfire potential increases significantly in the United States, South America, Central Asia, Southern Europe, Southern Africa, and Australia. Fire potential moves up by one level in these regions, from currently low to future moderate potential or from moderate to high potential. It is suggested that dramatic increases in wildfire potential will require increased future resources and management efforts for disaster prevention and recovery (Liu et al. 2010).

Deforestation

The impacts of deforestation on climate illustrate this complexity. Some studies indicate that deforestation could lead to decreased daytime temperatures and increases in boundary layer cloud as a consequence of rising albedo, transpiration, and latent heat loss. However, these effects are dependent on properties of both the replacement vegetation and the underlying soil/snow surface. In some cases the opposite effects have been suggested.

Forests contribute to the regional water cycle, with large potential effects of land-use changes on local and regional climates. On the other hand, forest protection can have drought and flood mitigation benefits, especially in the tropics. The effects of deforestation on precipitation are likewise complex and could be both negative and positive, dependent on land surface and vegetation characteristics.

Impacts of Climate Change on Groundwaters

Up to 80 % of rural water supplies are dependent on groundwater, providing safe water for 400 million people. This dependence is likely to increase as surface water sources become increasingly seasonal and demands from domestic, agricultural, and industrial users for reliable water increase. Groundwater storage comprises approximately 100 times the surface water storage and provides an important buffer against climate variability and change (MacDonald et al. 2011).

Groundwater and soil moisture collectively account for over 98 % of the available global freshwater resources. Groundwater levels correlate more strongly with precipitation than with temperature, but temperature becomes more important for shallow aquifers and during warm periods (Kundzewicz et al. 2007). Although groundwater systems are likely to respond more slowly to climate change than surface water systems, the impact of climate change on recharge, and hence long-term availability, remains unclear.

Climate change could modify groundwater recharge patterns as changes in precipitation and evaporation translate directly to shifts in soil moisture deficits and surface water runoff. Increases in rainfall intensity and evaporative demand would result in increased irregularity of groundwater recharge (Kundzewicz et al. 2007). However, groundwater recharge will also be affected by soil degradation and vegetation changes, both of which may be affected by climate and human drivers.

Limited information is available on groundwater conditions and trends, and present quantities and patterns of recharge of groundwater are uncertain. Moreover, long-term projections of rainfall and temperature reveal little about how groundwater recharge may change. Hydraulically effective rainfall contributing to groundwater recharge is affected as much by annual rainfall variation, the timing, intensity, and duration of rainfall events, as by total seasonal or annual amounts (Kundzewicz et al. 2007).

Impacts of Climate Change on Water Quality

Climate change affects water quality through both increased temperature and hydrological changes in rainfall affecting runoff and mobilization of nutrients and other pollutants. Heavy downpours increase the amount of runoff into rivers and lakes, washing sediment, nutrients, pollutants, trash, animal waste, and other materials into water supplies, making them unusable and unsafe. The increased water temperature will affect ice cover and circulation patterns in lakes and rivers as well as the rate of biogeochemical and ecological processes that determine water quality. In areas where river flow and groundwater recharge will decrease, water quality could deteriorate due to less dilution of pollutants. High intensity and frequency of floods and frequent extreme rainfall events increase the load of pollutants (organic matter, nutrients, etc.) washed from soils and overflows of sewage systems to water bodies. For example, in the northeast and midwest, increases in heavy rainfall events caused problems for the water infrastructure, as sewer systems and water treatment plants were overwhelmed by the increased volumes of water (Grimalt et al. 2001). This may results in:

(i) **Increased water temperature**: Since water temperature is mainly determined by heat exchange with the atmosphere, high air temperatures lead to high water temperatures. Water temperature may also be affected by other factors than air temperature. Especially in larger rivers, flow regulation, hot or cooling water from power plants, groundwater flow, extreme hydrological events, and high wind speed may be important (Moatar and Gailhard 2006).

(ii) **Water color:** Due to increased input of humic substances as dissolved organic carbon (DOC) from the catchment and through water runoff, the coloring is induced.

(iii) **Dissolved organic carbon (DOC):** Climatic factors may affect both concentrations and fluxes of DOC. These affect production of DOC in the terrestrial systems and thereby changing DOC concentration without changes in runoff. However, increased runoff may also affect DOC concentration through changing the degree of dilution and by altering water flow paths through soil. Drought and soil frost may also stimulate DOC production through increased fine root and microbial mortality, increased fragmentation of soil organic matter (SOM) and fresh litter, and increased aggregate instability, directly releasing DOC or increased microbial activity (Beltaos and Prowse 2009).

(iv) **Oxygen content:** Increased biological respiration results in low DOC, particularly in summer low-flow periods and in the bottom layers of lakes. High temperature and low oxygen concentration will cause stress and may decrease the habitats of cold-water species like salmonid fish in lakes and rivers. The DOC concentration decreases as a direct result of temperature rise but also as an effect of increased respiration, either as a direct response to increased temperature or due to increased nutrient levels (Bloomfield et al. 2006).

(v) **Increased nutrients:** Elevated mineralization and releases of nitrogen (N), phosphorus (P), and carbon (C) from SOM and increased runoff and erosion will result in increased nutrient loads. Release of P from bottom sediments in stratified lakes may increase due to declining oxygen concentrations in the bottom waters. A warmer climate can enhance the pollution load of nutrients to lakes and rivers to induce eutrophication. Changes in rainfall and resulting discharge patterns will also affect nutrient concentrations. Low summer flow will give less dilution of nutrients that affects higher nutrient concentration. High intensity and frequency of floods and more frequent extreme rainfall events will give increased surface runoff and erosion, increasing the nutrient load to the surface water. Heavy rainfall may account for a significant proportion of annual P transfer from agricultural soils under arable crops (Jeppesen et al. 2009).

(vi) **Underwater light conditions**: These are mainly affected by three factors: turbidity, DOC concentration, and phytoplankton density. Climate may change the underwater light conditions through changes in erosion, affecting both turbidity and background input of nutrients, and through changes in the carbon cycling processes in the catchment affecting the input of humic substances. Moreover, if the stratification pattern of lakes are changed, the depth of the circulating water column will be affected and thereby also the mean underwater light for phytoplankton.

(vii) **Salinization:** Increased erosion, runoff, and sewage discharge into water bodies could increase the concentration of salts in water which is highly hazardous to its inhabitants and users.

(viii) **Pathogenic microbes:** Sewage overflows upon heavy rains combined with high water temperatures and long ice-free season may increase the number of pathogenic microbes in water. High intensity rainfall may also give increased input of pathogens from pastures, rangelands, grasslands, drains, and treatment plants. Statistically significant correlations have been observed between rainfall and outbreaks of waterborne disease in both plants and animals including human beings.

(ix) **Hazardous substances:** Direct temperature effects will largely be limited to compounds which are volatile (organic pollutants, mercury) and/or subject to degradation processes. Climate change may affect future use of pesticides. It is not likely that changes in cropping patterns will affect the use of pesticides to a large extent. However, increased prevalence of existing pests, weeds, and diseases and increased pest resistance may lead to wider and more frequent application of pesticides and introduction of new products. On the other hand, in areas severely affected by drought, the decline in agriculture will lessen the use of pesticides. Increased temperature will increase the rate of dispersal and give wider distribution of pesticides (Bloomfield et al. 2006).

Climate change will also affect mineralization of previously released hazardous substances of soil and sediment. Increased frequency of intense rainfall events and floods will increase soil and sediment erosion and increase the pollutant concentration in aquatic systems (Bloomfield et al. 2006). More intense rainfall can also give more bypass flow and more rapid movement of pesticides from agricultural soils to surface water duly promoted by the negative change on soils. Loading of hazardous substances may increase due to sewage overflow and increased leaching of hazardous substances from urban surfaces resulting from increased rainfall.

Impacts of Climate Change on Water Resources of Pakistan

Pakistan is predominantly an arid and semiarid country. Pakistan is an agricultural country mainly dependent on surface irrigation through the Indus river system. The country has developed the world's largest contagious canal network. According to the climate change scenario, the warming is reflected in the river-flow data of

Pakistan, especially during the 1990s. In the post-Tarbela era, water diverted from rivers to the canal system has remained constant around 104 MAF per year. The freshwater outflow to sea may, therefore, be considered a good indication of the total river flow for this period. From the year 1975–1990, average flow into the sea has been 34.13 MAF per year. However from the year 1990 to 2000, this flow has been 47.88 MAF a year, i.e., about 40 % greater. For the winter season for the same period, average flow into the sea from the year 1975 to 1990 was 1.86 MAF a year. However from the year 1990 to 2000, this flow was 3.28 MAF a year, i.e., about 76 % higher. Although other factors may also be contributing, nevertheless the change visible in this time frame is quite large which is partially due to climate change. The global warming initially caused the river flow to increase as glaciers melt, then decrease as these recede. One more fact that emerges from the data is that when there is an excessive amount of water in summer, the succeeding winter also has more water than usual; this increased water availability in winter seems due to increased rains because of local effect of greater moisture in the soils and atmosphere.

An overall increase in rainfall of 50–150 mm has been recorded in summer monsoon belt for the period 1931–1990. But a decrease in rainfall was witnessed in the rest of country. Such decrease is 50–100 mm in western and northern mountains, whereas it is 25–50 mm in the southeastern and central parts. These variations are in line with the predictions of global warming which is expected to cause drier south and wetter north.

Naheed and Rasul (2011) used rainfall variability coefficient to analyze the past time situation from 1960 to 2009. The results of the decadal analysis showed high value of the variability coefficient in Balochistan (251 %), Sindh (247 %), and Punjab (208 %) provinces of Pakistan. However the annual analysis showed the increasing trend of variability coefficient from north to south. According to the inter-seasonal analysis, variation in the coefficient of variability was higher in post-monsoon and pre-monsoon seasons compared to the winter and monsoon seasons. This analysis showed that forecasting is a challenging job where the variability is prominently high (Naheed and Rasul 2011).

Droughts in one country or region also affect neighboring regions that otherwise are supposed to make surplus water available for interbasin transfers during the flood seasons. Increase in persistency of drought requires a reexamination of our assumptions, operating norms, and contingency measures for existing and planned water management measures. Droughts produce additional burden of migration of population from neighboring regions into lands that are already stretched to the maximum. Besides the social disruptions, there is the cost of the degradation of the natural resources due to their over-exploitation.

Adaptation Measures and Recommendations

Adaptation refers to the adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects to reduce the vulnerability and build the resilience of ecological and social systems and economic sectors to present and future adverse effects of climate change, which moderates harm or exploits beneficial opportunities (Parry 2007).

The relationship between adaptation and "normal" development is a subject of debate. Adaptation interventions often mirror ongoing efforts to promote sustainable development, making it hard to draw neat distinctions or, in terms of financing, to identify their incremental and/or additional cost over and above "development as usual."

Decreasing the Vulnerability of Water Resources

Development of human societies has involved a continuous process of adapting to changing stresses and opportunities. While climate change is seen as a relatively recent phenomenon, individuals and societies are adapting to a range of environmental and socioeconomic stresses. Adaptation aims at decreasing unavoidable adverse impacts in the shorter term, lowering vulnerability to present climate variability, and exploiting opportunities provided by climate change. Adaptation includes proactive and reactive measures, which relate mainly to planned adaptation as well as autonomous actions. Mitigation aims at avoiding the unmanageable impacts, while adaptation aims at managing the unavoidable impacts. In many parts of the world, especially in semiarid lands, there is good experience with phenomenon such as drought. As climate extremes are predicted to increase the frequency and intensity in future, it is important to understand and learn from relevant past adaptations and indigenous knowledge. The criteria to select adaptation measures and options for water are presented in Tables 1 and 2, respectively.

Adaptation Measures for Water Sector

Climate change poses a challenge to water managers by introducing uncertainty in future hydrological conditions. It may also be very difficult to detect an underlying trend, i.e., adaptation decisions may have to be made before it is clear how hydrological regimes may actually be changing. Water management in the face of climate change, therefore, needs to adapt a scenario-based approach.

Water Management Measures

These efforts include a wide variety of activities based on current and anticipated climate change impacts. Specific adaptation approaches include:

(i) Using water barrels that capture excess rainfall to minimize flooding and maintain a constant supply of water through dry spells
(ii) Improving irrigation systems and their efficiency
(iii) Protecting valuable resources and infrastructure from flood damage
(iv) Managing rainfall on-site to limit contamination and protect water quality
(v) Limiting development within vulnerable watersheds

Table 1 Criteria to select adaptation measures

Criterion	Sub-criterion	Guiding questions
Effectiveness of adaptation	Adaptation function	Does the measure provide adaptation in terms of decreasing impacts and exposure, enhancing resilience, or enhancing opportunities?
	Robustness to uncertainty	Is the measure effective under different climate scenarios and different socioeconomic scenarios?
	Flexibility	Can adjustments be made later if conditions change again or if changes are different from those expected today?
Side effects	No regret	Does the measure contribute to more sustainable water management and bring benefits in terms of alleviating the already existing problems?
	Win-win (or win-lose)?	Does the measure entail side benefits for other social, environmental, or economic objectives?
	Spillover effects	Does the measure affect other sectors or agents in terms of their adaptive capacity? Does the measure cause or exacerbate other environmental pressures?
Efficiency, costs, and benefits	Low regret	Are adaptation measures will bring high benefits relative to costs? (If possible, consider also distributional effects (e.g., balance between public and private costs) as well as nonmarket values and adverse impacts on other policy goals)
Framework conditions for decision-making	Equity and legitimacy	Who wins and who loses from adaptation? Who decides about adaptation? Are decision-making procedures accepted by those affected and do they involve stakeholders? Are there any distributional impacts of the climate change or of the adaptation measures?
	Feasibility of Implementation	What barriers are there to implementation?
		Technical
		Social (number of stakeholders, diversity of values and interests, level of resistance)
		Institutional (conflicts between regulations, degree of cooperation, necessary changes to current administrative arrangements)
	Alternatives	Are there alternatives to the envisaged adaptation measures that would be less costly or would have fewer negative side effects?
	Priority and urgency	How severe are the climate change impacts the adaptation measure would address relative to other impacts expected in the area/river basin/country? When are the climate change impacts expected to occur? At what timescales does action need to be taken?

Source: United Nations (2009)

Table 2 Some adaptation options for water supply and demand

Supply side	Demand side
Prospecting and extraction of groundwater	Improvement of water-use efficiency by recycling water
Increasing storage capacity by building reservoirs and dams	Reduction in water demand for irrigation by changing the cropping pattern, crop mix, irrigation methods, and area planted
Desalination of seawater	Reduction in water demand for irrigation by importing agricultural products
Expansion of rainwater storage	Promotion of indigenous practices for sustainable water use
Removal of invasive nonnative vegetation from riparian areas	Expanded use of water markets to reallocate water to high value uses
Water transfer	Expanded use of economic incentives including metering and pricing to encourage water conservation

Source: Parry (2007)

(vi) Precise weather forecasting and information network for farmers
(vii) Information exchange on new technologies at national and international levels
(viii) Managing aquifer recharge (MAR) is a technique for arid regions to replenish aquifers and allow subsequent recovery of water for urban, agricultural, and environmental benefit

Water Conservation Measures

Water conservation is an integral part of managing water resources. For regions experiencing population growth, water conservation can adjust current water use patterns to maximize existing water supplies. Water conservation can be achieved in several ways, varying greatly in terms of complexity, cost, and water quantity such as:

(i) Ensuring water conservation, lowering irrigation system losses, and providing incentives for adoption of more efficient irrigation techniques
(ii) Conserving water and minimizing runoff with climate-appropriate landscaping, such as xeriscaping
(iii) Promoting local watershed management systems
(iv) Expand floodplain areas, emergency flood reservoirs
(v) Introducing local rainwater harvesting measures
(vi) Efficient urban and industrial wastewater reuse

Upgrading Infrastructure

Upgrades and maintenance of water distribution and storage systems are among the most effective methods those can be employed for water conservation. Increase the capacity of existing water reservoirs (dams) and develop new ones for increasing water storage. Infrastructure upgrades consist of identifying and repairing leakages, conducting pressure adjustments, replacing aging infrastructure, and developing new ones within the existing urban water distribution system.

Exploring Alternative Water Resources

Desalination could provide an unlimited source of water. Saltwater desalination is a process of stripping salt, minerals, or other chemical entities from seawater to produce potable water. While the possibility of an unlimited supply is appealing, there are also various downsides associated with desalination. Though there are other desalinating technologies, we considered reverse osmosis (RO) desalination due to its increasing dominance worldwide. Recycling and reuse of municipal wastewater is also an effective source. Due to low precipitation and lack of perennial streams in dry areas, the most reliable water source for irrigation and industries is recycled wastewater.

Domestic Fixtures

Kitchens, toilets, sinks, and showers account for approximately 60 % of domestic water use on an average, so installation of water saving fixtures can significantly lower household water consumption. Therefore, for future generations implementation of water-efficient fixtures should be taken into account in new construction projects. We should also focus on water saving from a combination of fixtures at domestic level through public awareness.

Measures for Water Quality Control

All possible adaptive measures should be focused to prevent water pollution. All water management and conservation measures concentrated on decreasing runoff and floods should be adopted to minimize the entry of sediments, nutrients, pollutants, contaminants, trash, animal waste, sewage effluent, and other materials into water bodies and supplies; these could make waters unusable, unsafe, or in need of water treatment. Since higher intensity and frequency of floods and more frequent extreme rainfall events are expected to increase, the load of pollutants (organic matter, nutrients, and hazardous substances) washed from soils and overflows of sewage systems to water bodies (Grimalt et al. 2001). Four concrete water quality control aspects can be explained as:

(i) Measures for point source pollution control
(ii) Wastewater treatment and recycling
(iii) Measures for nonpoint source (agricultural) pollution control
(iv) Ecological restoration and eco-hydrology

(i) **Measures for Point Source Pollution Control**
Sewage treatment plants are one of the main sources of control. The main pollution problems associated with point pollution discharges are high temperature, organic and inorganic pollutants, and nutrients (nitrate, P, etc.). Uncontrolled or accidental discharge of untreated wastewaters into water bodies is particularly problematic from an environmental perspective, due to

its high levels of nutrients. The risk of this kind of discharge is particularly high in sewerage systems which combine storm water and wastewater; overflows of the system into water bodies, due to flash floods, for instance, can contain important amounts of untreated wastewater and several pollutants.

The decrease in point source pollution in view of these discharge pollutants is an effective adaptation measure. These types of measures are also recommended for limiting the risk of eutrophication in lakes, specifically targeting nutrient loading from point sources. In addition to environmental benefits, the measure has clear additional benefits for human health.

These include:

(a) **Nitrate and phosphate load in wastewaters**
The N and P present in wastewaters can lead to eutrophication of surface waters. Climate change increases this risk due to low river flows and increased frequency of flash floods – with increased storm and sewage overflow – predicted for some regions. One measure addressing this is banning or minimizing of phosphate in relevant domestic products and industrial processes. Phosphorus reclamation is considered an effective solution for maintaining high water quality in a changing climate and delivering economic benefits at the same time.

(b) **Separation of rainwater and sewage**
Untreated wastewater reaching surface waters constitute a serious pollution problem. A possibility, both when building new canalization and renovating existing drainage, is to separate wastewater and storm water. This is a comparatively expensive option, but it will strongly lower the risk of untreated wastewater entering the water systems.

(c) **Improvement of wastewater infrastructure capacity**
In many regions, the frequency of flash floods is expected to increase due to climate change. Improvements in the capacity of treatment plants or in storage capacity can address this problem.

(d) **Incorporating climate change considerations into discharge licensing schemes**
New forms of discharge license agreements include provisions that address uncertainty due to climate change. Licenses from point source discharges should be reviewed periodically; changes related to climate change impacts as well as in other parameters such as population behavior and available technology can thus be reflected in the revised agreements. In the United Kingdom, discharge licenses of wastewater treatment plants are reviewed every 5 years to this purpose. Changes to the system's carrying capacity to address climate change will be reflected in the pollution load the system is allowed to take up.

(ii) **Wastewater Treatment and Recycling**
Sewage treatment plants are one of the main control measures of point pollution. Uncontrolled or accidental discharge of untreated wastewaters into water streams is particularly problematic from an environmental

perspective due to its high levels of nutrients and other toxic substances. Such discharge is particularly high in sewerage systems which combine storm water and wastewater. They also overflow system into water bodies due to flash floods and can contain significant amounts of untreated wastewater and pollutants. Both domestic and industrial wastewater treatment and agricultural wastewater treatment and seawater treatment are effective measures for pollution control. The treated water reuse for drinking, irrigation, or industrial processes is also a potential adaptive practice.

(iii) **Measures for Diffuse Pollution Source Control**
Agriculture is the main source of diffuse pollution affecting water bodies. Conventional agriculture implies a certain level of leaching or washout of nutrients and pesticides, either to surface waters or to groundwater. Some pollutants (P, metals) adhere to soil particles and could reach surface water bodies as soil particles are transported due to erosion. Vegetated and unfertilized buffer zones alongside water courses act as a shield against overland flow from agricultural fields and decrease runoff from reaching the water course, thus decreasing erosion and the movement of pollutants into water courses.

Agricultural measures that limit erosion and leaching and aim at water conservation decrease the input of solid and suspended particles into water bodies and consequently the input of diffuse agricultural pollutants. These measures also have the potential of lowering the runoff from agricultural fields. Some of these measures are discussed in section "Adaptation Measures for Agriculture Sector."

(iv) **Ecological Restoration and Eco-hydrology**
Identify the ecosystems that are most vulnerable to climate risk and then the best available measure on climate-induced impacts to engage with vulnerable groups including assessment hazards, vulnerabilities, and capacities that can support adaptation planning (Reid and Huq 2007). Adapt appropriate measures to preserve the ecology of risk areas.

Policy Measures

(a) Assess and address the needs for additional water storage and distribution of infrastructure.
(b) Ensure early rehabilitation, remodeling, and upgrading of the existing irrigation infrastructure in the country to make it resilient to climate change-related extreme events.
(c) Identify new potential dam sites to keep the option open to develop new dams, should they be needed.
(d) Develop necessary infrastructure to harness the potential of hill torrents.
(e) Enforce measures to enhance the life of existing storage facilities.
(f) Thus, policy coherence with the agricultural policy's provisions should be ensured with regard to adaptation objectives in water management.

Integrated Water Resource Management

(a) Ensure that, in making water allocations (within gross national availability) to various sectors in the medium to long term, due consideration is given to changes in sectoral demands caused by climate change.
(b) Protect groundwater through management and technical measures such as regulatory frameworks, water licensing, slow action dams, artificial recharge especially for threatened aquifers, and adoption of integrated water resource management concepts.
(c) Ensure rational groundwater exploitation by avoiding excessive pumping.
(d) Ensure recycling of wastewater through proper treatment and its reuse, for example, in agriculture, artificial wetlands, and groundwater recharge.
(e) Protect and preserve water catchment areas and reservoirs against degradation, silting, and irrigation system contamination.
(f) Encourage active participation of farmers in water management along with line departments by accelerating implementation of participatory irrigation management reforms.
(g) Ensure water distribution among provinces as far as possible in accordance with crop sowing timings.
(h) Address seawater intrusion into the coastal region by allocating the requisite water flow downstream.
(i) Take appropriate measures to preserve the ecology of dry river reaches.
(j) Develop contingency plans for short-term measures to adapt to water shortages that could help mitigate drought.
(k) Explore the possibility of joint watershed management of trans-boundary catchment areas with neighboring countries.
(l) Safeguard Pakistan’s rights on trans-boundary water inflows according to international norms and conventions.
(m) Promote integrated watershed management including ecological conservation practices in uphill watersheds.

Legislative Framework

(a) Legislate and enforce industrial and domestic waste management practices to protect the environment, in particular water resources, from further degradation.
(b) Enact and enforce laws and regulations required for efficient water resource management and a groundwater regulatory framework.
(c) Protect the Hindu Kush-Himalayan (HKH) glaciers, considered the world’s water tower, by declaring them as “protected areas” through agreements among countries sharing the Himalayan region.

Adaptation Measures for Forests

(i) Pest control: The biological control of forest pests is a very important adaptation measure.
(ii) Promote farm forestry.
(iii) Special attention should be given to those tree species which have poor seed production and dispersal, occupy ecological niches, have small populations and restricted ranges, and are peripheral.
(iv) Preservation of watersheds to control sediments downstream.
(v) Control of wastage as the use of waste wood to produce composite wood (Joseph and Tretsiakova-McNally 2010).

Adaptation Measures for Agriculture Sector

Agriculture is a sector that can make large contributions to adaptation to climate change and water quantity as well as quality. The following measures should be promoted:

(i) **Support for switching to organic farming**
Organic farming strongly limits the possibility of agriculture-related pollution entering groundwater or surface water bodies. In addition to restrictions typically prohibiting the use of pesticides and fertilizers and regulating the use of natural fertilizers, requirements also typically include rules for improved soil structure and functioning, thus reducing the risk of soil erosion and unwanted sediment transport.
(ii) **Precision farming**
Precision farming is based on the principle of meeting crop requirements as precisely as possible, using high technology (Global Positioning System yield mapping, variable rate delivery of seed, pesticides, and fertilizers) at a very fine scale (a few square meters) and aiming for application at the best possible moment in time. This results in maximization of efficiency of all inputs and reduces the risk of nutrient and pesticide runoff to surface water, leaching to groundwater, etc.
(iii) **Erosion reduction measures**
  (a) **Continuous plant cover (catch crops, intercrops)/winter plant cover:** A cover crop will take up residual nitrate (NO_3^-) and other nutrients from soils and help stabilize soil thus decreasing soil erosion and the mobilization of associated pollutants.
  (b) **Green stripes between fields:** Establishment of green stripes of some meters wide between agricultural fields, either with permanent or with temporary (yearly) cover crops, could decrease the erosion of field soil and surface runoff, thus the input of nutrients and pesticides into surface waters.

(c) **Mulch sowing:** Maintaining plant parts after removing seed within the soil and abstaining from the use of ploughs naturally creates a protective layer of mulch while new plants are sowed directly into the soil. This helps maintain organic matter and preserve good soil structure, thus improving infiltration and retention of water and thereby decrease erosion and pollutant concentrations in surface runoff.

(d) **Preventing soil compaction:** Soil compaction lowers water infiltration into soils, thus favoring surface runoff and erosion; compaction-free soils are also more drought resistant for crops. Options for preventing compaction include use of low ground pressure tires or tracks on vehicles, avoiding wet soils, and adding organic matter to soil.

Agricultural measures that decrease erosion and/or aim at soil conservation lower the input of solid and suspended particles and pollutants into water bodies. Some of these measures (e.g., winter plant cover) also absorb soil nutrients, reducing the nutrient load available for leaching. The measures also have the potential of strongly limiting the runoff from agricultural fields.

(iv) **Fertilizer, manure, and slurry management measures**

A rational and planned application of fertilizers/manure/slurry, which is well timed and which takes account of local parameters such as soil type and structure, is a widespread tool for reducing nutrient leaching and can have an enormous impact on water quality. These management measures include:

Nutrient balance: Nutrient balance spreadsheets inform farmers on the efficiency of nutrient utilization and help identify the cropping phases in which nutrients are lost. These help to accurately account for fertilizer use and decrease unnecessary nutrient inputs. The reductions have positive effects on both surface and groundwaters.

Manure application techniques: These involve, for instance, cutting slots in soil, injecting slurry, and then closing these slots after application. These lower groundwater and surface water pollution from NO_3^- leaching and phosphate runoff.

Integration of fertilizer and manure nutrient supply: Determining the amount of nutrients supplied to soils during manure application helps farmers judge the amount and ideal timing of additional fertilizers required by the crop. Taking better account of the nutrients contained in manure can reduce the need for fertilizer inputs, which in turn minimizes NO_3^- and P losses.

(v) **Risk-based fertilizer and manure restrictions**

Risk areas include areas with flushes draining to a nearby water course, cracked soils over field drains, or fields with a high P index. By avoiding the spreading of mineral fertilizers or manure at high-risk times, the NO_3^- leaching and loss of P through surface runoff is diminished. High-risk times include when there is a high risk of surface flow and rapid movement to field drains from wet soils or when there is little or no crop uptake.

(vi) **Precision techniques**
Additional options include the adoption of improved precision techniques such as soil analysis, manure analysis, adaptation of fertilizer and pesticide application on demand, matching fertilizer to seasonal conditions, and slow- and controlled-release fertilizers.

Cash Crops

Cash crops are usually sown after the harvest of one crop and before the sowing of the next. They offer forage or green manure (providing fertility for the soil thereby reducing N applications for the next crop) potential and are usually based on quick growing plants that will establish before winter. Their mitigation benefits include reducing N_2O emissions or leakage, improving N-use efficiency and carbon sequestration in the soil (Lal 2008).

Cropping Patterns

- Adjusting cropping pattern with water availability and water conservation
- More share of cropped area under oil seed crops and crops having less water requirement
- Improving productivity and production management
- Promoting farm forestry

Effective Irrigation Systems

Ensure water conservation, decrease irrigation system losses, and provide incentives for adoption of more efficient irrigation techniques:

Conserving water and minimizing runoff with climate-appropriate landscaping, such as xeriscaping, striping, or contouring
Improving irrigation systems and their efficiency
Improving water-use efficiency by recycling water

Strategies for Implementing Adaptation Measures

To maintain water supply and conservation as well as successful adaptation programs, the main strategies could be:

(i) Research initiatives
(ii) Planning and policies
(iii) Public awareness
(iv) Enhancing capacity
(v) Technology transfer
(vi) Follow-up programs after field demonstration by experts

The following measures should be adopted regarding this aspect:

(a) Develop and extend water-efficient technologies and techniques for seawater utilization, water recycling, and avoiding wasteful use of domestic and drinking water.
(b) Ensure measurement and monitoring of irrigation water delivery at various points of the supply system for effective planning and management.
(c) Enhance national capacities in remote sensing and GIS techniques for monitoring temporal changes in glaciers and snow cover.
(d) Enhance national capacities for making seasonal hydrometeorological forecasts, particularly for monsoon rainfall.
(e) Prepare a comprehensive inventory of all water resources, including surface and groundwater, in order to support an efficient water management system in the country.
(f) Strengthen the current hydrological network to monitor river flows and flood warning systems.
(g) Devise and strengthen coordination mechanisms among national and international water sector institutions.
(h) Promote public awareness campaigns to underscore the importance of conservation and sustainable use of water resources.
(i) Enhance research activities and facilities regarding these aspects to accelerate adaptation.
(j) Linking science, management, and policy in climate change and water resources.
(k) Cost-effective, adaptive water management and technology transfer to all stakeholders.
(l) Capacity building and institutional strengthening.
(m) International and regional cooperation.

Mechanisms to Achieve Solutions

(i) **Education and awareness:** Goals of education and awareness building efforts, connecting people to water quality impacts, documenting the problem, engaging the community, working with the media, and advocacy with policy makers and agencies.
(ii) **Monitoring/data collection:** Problems with water quality data.
(iii) **Governance and regulation:** Water reforms, policies, laws, and regulations; establishing water quality standards; international water quality guidelines; international governance and law; managing trans-boundary waters; financing water quality; institutional capacity building; and strengthening enforcement.
(iv) **National strategies:** Provide the framework for adaptation actions, many of which have to be implemented at subnational and local levels. The relevance of adaptation at the national level is primarily concerned with coordinating information sharing and encouraging an appropriate, proportionate, and

integrated implementation of adaptation measures at different levels. The integration of adaptation into national sectoral policies and structural/cohesion funds together with fostering research and involving stakeholders are key instruments in this respect (Shardul and Samuel 2008).

Implications for Adaptation Process

It is possible to define five different types of limits on adaptation to the effects of climate change (Parry 2007):

(i) Physical or ecological: It may not be possible to prevent adverse effects of climate change through technical means/institutional changes, e.g., it may be impossible to adapt where rivers dry up completely.
(ii) Technical, political, or social: It may be difficult to find acceptable sites for new reservoirs or water users to consume less.
(iii) Economic: An adaptation strategy may simply be too costly in relation to the benefits achieved by its implementation.
(iv) Cultural and institutional: These may include institutional context within which water management operates, the low priority given to water management, lack of coordination between agencies, tensions between different scales, ineffective governance, and uncertainty over future climate change; all act as institutional constraints on adaptation.
(v) Cognitive and informational: Water managers may not recognize the challenge of climate change or may give it low priority compared with other challenges. A key informational barrier is the lack of access to methodologies to cope consistently and rigorously with climate change.

Feedbacks from Adaptations to the Global Environment

In attempting to adapt implementation systems to cope with climate and other environmental changes, it will be important to ensure that changes proposed do not exacerbate climate change or other aspects of environmental degradation. Past intensification (land cover change, especially the removal of trees) has made a large contribution to CO_2 emissions. Hence one means of mitigating further greenhouse gas emissions is to intensify vegetation production on existing cleared areas and leave forests intact.

A series of adaptation measures are under way to counteract these negative impacts, such as improved point source control and measures to decrease nonpoint pollution especially agricultural measures, change of industrial processes to lessen effluents, banning P in detergents, and restoration measures in rivers and lakes. The uncertainty is whether these will be sufficient and be implemented soon enough to prevent these negative impacts on the inland waters of globe.

Conclusions

The aim of this chapter was to provide an overview of the climate change impacts on water resources in dry regions and propose possible adaptation measures to mitigate these impacts. Climate change drivers directly or indirectly affect water availability by altering precipitation patterns, increasing evaporation and atmospheric water vapor, melting glacier snow and ice, raising sea level, and causing changes in soil moisture, groundwater recharge patterns, surface runoff, and river discharge.

Climate change also result in significant deterioration of water quality by altering physical, chemical, and biological characteristics of water, thereby leading to a load of pollutants including sediments, salts, organic matter, nutrients, hazardous substances, and pathogens. Changes in the water resources lead to impacts on all the socioeconomic features such as energy production, infrastructure, food availability, health, agriculture, and environment.

A number of approaches, including water management and conservation, infrastructure upgrading, exploring alternate resources, and recycling wastewater, have been proposed to facilitate the adaptation planning and implementation process. In terms of water quality, all potential management, conservation, and control measures for both point and nonpoint sources should be adopted to minimize the entry of pollutants and contaminants into water bodies and supplies.

Extending access to reliable and affordable water in terms of quantity and quality remains key to strengthening livelihoods and building resilience to climate change. Therefore, it is need of the hour that an effective adaptation program through all potential integrated measures at local, national, and global scales should be initiated or enhanced under current and future water scarcity circumstances.

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Climate Change Vulnerability to Rice Paddy Production in Bali, Indonesia

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Abstract

This chapter presents the recent vulnerability assessment project on a rice paddy production and climate change in Indonesia and attempts to demonstrate a practical framework and methodology for a vulnerability and adaptation assessment in the agricultural sector. This chapter applies the outcome vulnerability framework, which is defined by the IPCC. The framework is applied into a practical methodology using multidisciplinary approaches such as statistical modeling, GIS and remote sensing, as well as participatory research, focus group discussion, and policy assessment. The chapter produces vulnerability maps illustrating how climate change affects rice paddy production in Indonesia especially Bali island. In Bali island, the suitability for rice paddy production has been decreased 20 % in the last 20 years because of changes in climate, and climate change will continue in the future. On the other hand, the chapter suggests that actual damages will be based on rice paddy location and the adaptive capacity of farmers. The chapter demonstrates the impacts of climate change on rice paddy production, which is a staple food for many developing countries including Indonesia. It is important to understand the impacts of climate change in agriculture sector that is the most vulnerable to adverse changes in climate. The chapter successfully demonstrates a multidisciplinary approach, which can be applied in other agricultural products in different countries.

Keywords

Vulnerability assessment • Climate change • Agriculture • Rice production • Multidisciplinary approach • Indonesia

Introduction

This chapter assesses the vulnerability of rice paddy production on Bali island, Indonesia, and creates a climate change vulnerability map. The present assessment includes the three subcomponents that are required for climate change vulnerability: exposure, sensitivity, and adaptive capacity. The assessments of exposure are based on climate data from BMKG, such as annual rainfall, temperature, and humidity. The data regarding paddy location are used as an element of sensitivity. Adaptive capacity assessment employs a normative approach to determine paddy production, such as mixed qualitative and quantitative techniques.

The devastating impact of climate change has already been evident in Indonesia. The country's combination of high population density, high levels of biodiversity, having more than 15,000 islands, and having a coastline that stretches over staggering tens of thousands of kilometers makes Indonesia one of the most vulnerable countries to the impact of climate change. Bali, a small island of Indonesia, is likely to suffer from rising sea levels, droughts, and floods, which will impact the island's rice production. In general, the production of paddy has decreased since year 2000. Decline in paddy's production is in line with the shrinking of harvested areas for paddy. In contrast, the production rate has been increased; therefore, it negates the reduction of total yield level. From years 2000 to 2008, the harvested area has been reduced 7.1 %, productivity rate increased 8 %, and production size increased 1.6 %. The paddy production may not be able to rise or may even shrink in the future if paddy areas, production rate, or production cycle is reduced by climate change (Takama et al. 2012). Rice is one of the most important agricultural crops in Indonesia, and it can be affected by climate change just as other agricultural products can be (Centennial Group International 2012).

This chapter demonstrates the approach and the results of a vulnerability assessment for climate change and rice paddy production. This approach uses qualitative and quantitative assessment methods and relevant maps of the assessment. It also helps researchers to make policy recommendations based on the assessment. The approach will be transferable to other regions of Indonesia as well as many developing countries.

Background

Vulnerability Assessment

The IPCC (Intergovernmental Panel on Climate Change) gives the most frequently quoted definition of vulnerability: "Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (2007, p 883). Extensive climatic and socioeconomic vulnerability may worsen the plight of poor farmers who comprise the majority of rural populations in developing countries such as Indonesia, and farmers will continue to be vulnerable to social and weather changes in the immediate future. It is believed that the earth is warming, and climate change on a global scale has already been observed. As a result, disasters, especially drought, hurricanes, and floods, occur more often and hinder agricultural activities. According to a report created by the Asian Development Bank, weather-related disasters in Southeast Asia will increase (Yusuf and Francisco 2009). However, "rise in disaster" does not mean "rise in vulnerability," because the concept of vulnerability is often defined based on exposure, sensitivity, and adaptive capacity. Exposure is the likelihood that climate-related disasters will happen to a target group (i.e., an exposure unit), including droughts and floods. Sensitivity can be defined as an exposure unit's susceptibility and is represented by rice paddy field density, population density, etc. Adaptive capacity is defined by the IPCC as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2007) and is usually estimated by social factors, financial resources, and climate-proof infrastructures.

The social factors that are included in assessments of adaptive capacity are not related to climate, but they are closely related to the climatic impacts on rice paddy production. For example, a meteorological drought can occur in a rice paddy location, but the rice paddy will not be damaged if the farmers know how to cope with the impact, if they understand how to apply seed variety choice, and if they enforce policies adequately (Liverman 1990; Meze-Hausken 2004; Ifejika Speranza et al. 2008). In other words, when farmers possess high adaptive capacity, they can minimize the impacts of droughts. Therefore, it is important to include adaptive capacity based on social factors in a vulnerability assessment.

This report assesses separately the three components of the vulnerability assessment, because the natures and the measures of these three components (i.e., exposure, sensitivity, and adaptive capacity) differ. For example, exposure is climate stresses or potential climate-related disasters, so exposure is difficult for humans to reduce and might even be impossible for them to eliminate. Some reports mention terms like "reducing exposure through building a dike in the case of sea level rise" (Know Climate Change 2004). However, building a dike is not reducing exposure, but is, instead, improving adaptive capacity, because it is not possible to stop the sea level from rising beyond mitigation measures, such as the reduction of greenhouse gasses. Although it is not possible to tackle exposure directly, information about exposure is important. Without exposure information, it is not possible to know where potential disasters will happen or at what magnitude. It would be a waste of resources to build an irrigation system in an area where drought is unlikely to occur or to construct a dam where there will be no flood. Exposure indicates the areas of potential disasters and thus helps policymakers and stakeholders to decide how to prepare for climate change.

Normative Index Development Process

Some analysts expect vulnerability assessments of climate change to be objective (Nagel 1989). However, it is neither possible nor desirable to be purely objective when each assessment includes social issues and the desires of a number of stakeholders (Schwandt 2000; Johnson and Onwuegbuzie 2004). Therefore, a vulnerability assessment needs a normative approach so that the researchers can work with the local stakeholders.

Climate change is about the future, so the vulnerability problems in question have not occurred in most cases. In addition, developing a vulnerability map requires quantitative information, because it compares factors and locations. Quantitative techniques are neither appropriate nor outperform qualitative methodologies in terms of exploring normative questions, such as "What kind of issues usually concern farmers and policymakers?" or "What are the key factors that might affect paddy production in a particular area?" Therefore, it is important to conduct further exploratory research to answer these normative "what" questions before working on quantitative assessments. Similarly, to calibrate the quantitative results so that they fit the needs of the users and to make the results transplantable, discussions with key stakeholders are necessary.

Moreover, the process is bound to be politically sensitive to policymakers and stakeholders. Fortunately, constructing the indicators through an objective and scientific process results in fewer arguments. A normative index development involves subjective judgments, because vulnerability assessment must include judgments, such as which weather conditions would be "good" or "bad" for paddy production (Takama et al. 2012; Adger et al. 2004; Harvey et al. 2009). In the normative process, stakeholders can discuss their thoughts and priorities to develop the index collaboratively. Another advantage of the normative index is that it is more likely to be accepted by its users because they have contributed to the process of indicator development (Giovannini 2008).

Methods

Weighting Between Exposure, Sensitivity, and Adaptive Capacity

Many vulnerability assessments use three components to express vulnerability, and they are usually exposure, sensitivity, and adaptive capacity. Among16 recent vulnerability assessments conducted by the ADB, UN, World Bank, etc., almost all of them used equal weighting among the three major components, i.e., 1/3, 1/3, and 1/3 (e.g., Yusuf and Francisco 2009; Heltberg and Bonch-Osmolovskiy 2011; WHO 2011). The equal weighting may not produce the optimal end result, but assessing with equal weights is a reasonable starting point. Weighting factors within each component can be assessed with a scientific or a social scientific method. However, weighting among the three components can be too complicated or too political to be determined scientifically. The three components are organized in terms of similarities in their characteristics. Therefore, it is easier to apply the same domain of science and social science techniques to estimate weight within a component. For example, agriculture's exposure to potential disasters can be defined by the FAO's soil suitability assessment or other agricultural drought assessment techniques (FAO 1976; FAO and UNESCO 1990). In many cases, sensitivity can be defined as a statistical proportion, namely, the density of a target exposure unit, including human settlements, rice paddy density, and protected ecosystems (Yusuf and Francisco 2009). Social science assessment techniques are usually applied to estimate the weight within adaptive capacity (Ziervogel et al. 2006; Takama et al. 2012). In contrast, the characteristics of these three components are significantly different, so it is difficult to implement well-defined science or social science techniques. As a result, the weighting among the three components is evaluated in a less scientific way, such as with expert opinions and stakeholder meetings (Vincent 2004; Vincent 2007).

Equal weighting has significant biases. Heltberg and Bonch-Osmolovskiy (2011) and Eakin and Bojorquez-Tapia (2008) mentioned that equal weighting makes an implicit judgment about the degree of influence of each indicator and that it is normative and not as objective as other approaches. Therefore, the researchers of this report initialized the weighting of the three subcomponents as equal and then calibrated the weighting while discussing the results with experts and stakeholders (Savonis et al. 2008).

An index within each component is composed of a unique number of factors and weights that are estimated with approaches that are more scientific and social scientific in nature. The three components use different units and scales. For example, when a paddy area density is used as sensitivity, the unit is a percentage between 0 and 1, and the adaptive capacity is the production gain in kg/acre. Therefore, it is necessary to normalize and standardize these subindexes into a common unit such as [0, 1] for the final integration. The project tested multiple scientific techniques such as z-score normalization and minimax standardization (see more in Giovannini (2008) and CARE International (2009)) ranking based that was used by WFP (2009) were implemented for the standardization and color categorization. Moreover, values for adaptive capacity should be inversed, because the vector/direction of adaptive capacity is the opposite of the other two components. High exposure and high sensitivity mean high vulnerability, whereas high adaptive capacity means low vulnerability.

A weighting factor development starts with a prototype that is developed through qualitative stakeholder meetings (Takama et al. 2012). After the appropriate stakeholders were identified for the present study, the prototype was updated to reflect the users' needs and the non-captured reality from the stakeholders' and experts' viewpoints. For example, a stakeholder workshop was conducted with provincial and district agriculture agencies, a cultural agency, a public work agency, Udayana University, Technology Research on Agriculture, head of subak (*pekaseh*), and Indonesian Met Office (BMKG) in Denpasar. This workshop helped to finalize the components and the weight of the vulnerability and to make the models more useful and more accessible to nonexperts and stakeholders.

Livelihood Zone Map

Before the social surveys were conducted, the livelihood zones were assessed to understand the characteristics of farmers and livelihoods in Bali and to determine the survey locations (Food Economy Group 2006; Selvaraju and A.D.P. Center 2006). A livelihood is a means of living through assets (e.g., livestock, land, forest, and ships), activities (e.g., grazing land, fishing, and wage labor), and capabilities, which is the product of assets and activities. Livelihoods vary by location due to the fact that the livelihoods of many Indonesian farmers are determined by geography, agricultural potential, and market access.

Geography affects production through climate, soil, and topography and dictates marketing/trade activities through roads and proximity to urban centers. The household production of food and other items may either be directly consumed or may be traded/exchanged for other items in the market. Market access determines the ability of people to trade their goods, such as crops, livestock, or other items, to sell their labor and to obtain the prices that they desire. Factors that do not determine livelihood zones are man-made factors, such as poverty, wealth, conflict, healthcare, education, and other governmental and nongovernmental services (USAID 2009). In this study, more weight was placed on geographical characteristics, including precipitation, topology, and types of agricultural production. A complete step-by-step guide was developed by the Food Economy Group (2006), and an assessment with climate variability has also been implemented by FAO (Selvaraju and A.D.P. Center 2006).

Exposure

Exposure was measured with FAO's soil-climate suitability index (FAO 1976; FAO and UNESCO 1990; FAO 2001). The suitability method indicates the potential damages related to climate factors; therefore, it is appropriate for measuring exposure factors. Simplicity is not necessarily inaccurate. Izumi et al. (2013) predicted the global rice yield from only estimated soil moisture and the temperature of cultivation areas. The verification revealed that the model predicted good results in 20 % of the rice growing regions in the world from 1982 to 2006. The categorization is based on a report from the Indonesia Ministry of Agriculture (Subagyono et al. 2003) and is summarized in Table 1. In short, lowland rice can be grown at an altitude of 0–2,500 m above sea level, and the physical and chemical properties of acceptable soil can vary greatly from a sandy to clay soil texture, a pH of 3–10,and an organic matter content of 1–50 %. The soils can also include different levels of available nutrients. Rice needs enough radiation intensity during the reproductive and ripening phases.

Sensitivity

In this case, sensitivity was defined as paddy field density. This approach is similar to what ADB did for their South East Asia vulnerability assessment project (Yusuf and Francisco 2009). ADB's report defined human sensitivity and ecological sensitivity as the population density and the percentage of protected ecological areas, respectively. Areas with more human settlements and more biodiversity are more vulnerable to the same level of exposure than areas with fewer humans and less biodiversity. Sensitivity indicates the general likelihood that an area will be affected. Climate change is often believed to impact areas with high exposure and high sensitivity. For example, if drought is expected in a large area, policymakers should focus on the places with more rice paddies or more people rather than the places with few rice paddy fields or people. Therefore, sensitivity information is very valuable.

The paddy areas were defined with remote-sensing techniques that acquire information by utilizing devices that have no physical contact with observed objects, regions, or phenomena (Boschetti et al. 2009; Gumma et al. 2011; Wayan and Nishio 2007, Nuarsa et al. 2010, 2011, 2012; Sari et al. 2010; Shao et al. 2001; Uchida 2010; Xiao et al. 2005). The sensitivity as paddy field density was defined by dividing the rice paddy area by total land areas in each kecamatan (subdistrict). There are 39 kecamatan in the Bali province.

Table 1 Suitability of land for rice (Oryza sativa) commodity (Subagyono et al. 2003)

Land requirements/characteristics	Class of land suitability			
	S1: high suitability	S2: mild suitability	S3: low suitability	N: not suitable
Average temperature (°C)	24–29	22–24	18–22	<18
		29–32	32–35	>35
Rainfall (mm):				
First month	175–500	125–175	100–125	<100
		500–650	650–750	>750
Second month	175–500	125–175	100–125	<100
		500–650	650–750	>750
Third month	175–500	125–175	100–125	<100
		500–650	650–750	>750
Fourth month	50–300	30–50	<30	
		300–350	500–600	>600
Humidity (%)	33–90	30–33	<30 > 90	
Oldeman climate type	A1,A2,B1,B2	A1,A2,B1	C1,C2,C3	D1,D2, D3,D4,E
		B2,B3		
Altitude	<500 m	<750 m	<1,000 m	<1,000 m
Land physics:				
Slope (%)	<3	3–8	>8 up to 25	>25
Texture	Smooth, quite smooth, mild	Smooth, quite smooth, mild	Quite rough	Rough
	5.5–8.2	5.0–5.5	<5.0	
pH H2O		8.2–8.5	>8.5	
Peat:				
Thickness (cm)	<60	60–140	140–200	>200
Thickness (cm) if there is insertion of mineral material	<140	140–200	200–400	>400

Adaptive Capacity

Adaptive capacities include the functions of socioeconomic factors, technology, and infrastructure. To obtain factors that can be used for adaptive capacity, the researchers conducted a stakeholder meeting, expert discussion, and a survey of rice farming in Bali. Issues, objectives, and potential impacts were explored beforehand, as explained by Takama et al. (2012). Based on these identified issues and the livelihood zone analysis, a survey was designed to model adaptive capacity. Secondary data were also collected after distinguishing significant factors. A model was developed with a normative approach, which is the combination of the statistical assessment, expert opinions, and stakeholder meetings. The purpose of the survey and statistical analysis is to quantify the importance of the factors that influence the productivity of paddies. The factors are used as the elements of adaptive capacity. The potential factors identified by a statistical assessment were justified during stakeholder meetings and expert judgment.

A household survey was conducted to learn the farmers' adaptive capacities and perceptions of climate change. The questionnaire is mainly based on WFP's household questionnaire, which they used in their pilot food security and nutrition monitoring system project in Indonesia as well as in other similar studies (WFP, Ministry of Agriculture (Kemtan) 2009). A field survey was conducted in July and August 2012 by visiting 490 farmers at 70 subaks that are located at 81 villages in seven livelihood zones. The survey locations were chosen based on a clustered stratified random sampling method. Ten subaks in each livelihood zone were selected to represent upper, middle, and downstream areas. An ordinal least square regression model was implemented for the preliminary parameter identification, and other statistical tests were conducted on the survey data. The regression model for adaptive capacity, which is used to estimate the weighting factor, was finalized with the preferences approach, including expert interviews and a stakeholder discussion (Hinkel 2011; Harvey et al. 2009, p 17).

Results

Exposure

Bali is one of the leading rice-producing areas in Indonesia. With East Java, Bali produces 22 % of the rice produced in Indonesia (Naylor et al. 2007). Compared with other regions of rice cultivation, Bali is characterized by a short rainy season. For example, a typical rainy season in North Sumatra starts in early September and lasts until early June, but Bali's rainy season begins in late November and ends in late April. Thus, Bali is more likely to face water shortages, which is unfortunate, because it is an important region for rice production in Indonesia. It is said that the northern and eastern parts of Bali are particularly susceptible to drought (Fig. 1).

Impact of Climate Change on Rice Production

Based on a policy assessment with 10 governmental reports, including the National Action Plan and the Medium-Term Development Plan, there are 23 sets of adaptation policies in relation to agriculture (Takama et al. 2012). This is the largest number in the five major sectors, which also include water resources, coastal, ecosystems, and health. For example, the National Action Plan (2007) mentions the importance of developing an early warning system for drought. The fifth Presidential Decree in 2011 is also about climate change impacts on paddy production. As a result, examining the vulnerability of climate change on rice production is a priority in Indonesia.

Because of the warm climate, two or three cropping cycles in a year is possible in Indonesia. From the beginning of the rainy season until the beginning of the dry season, Balinese farmers usually cultivate rice twice. Then, they harvest vegetables

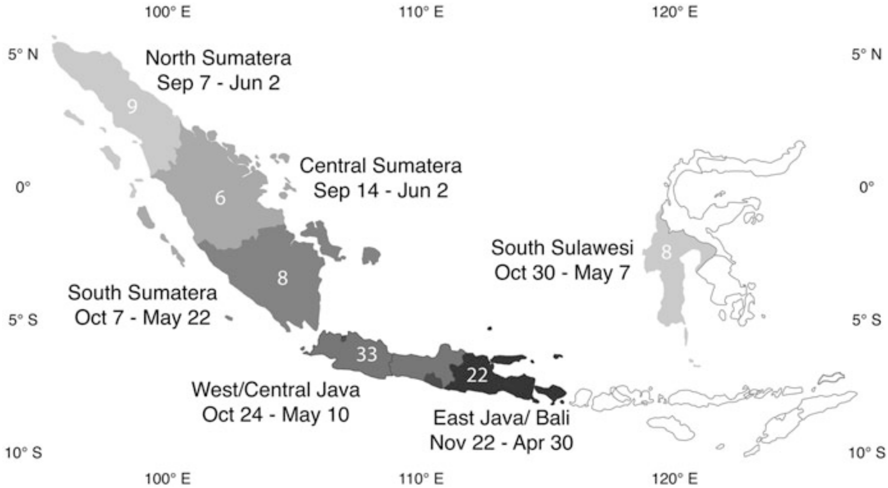


Fig. 1 Periods of a wet season and the proportion of paddy production in Indonesia. Numbers in the figure indicate the percentage of rice paddy production in Indonesia. The dates indicate the wet season periods. For example, East Java and Bali produce 22 percents of rice in Indonesia and a wet season starts from 22 November and ends 30 April on average

once before the rainy season begins. If there is not enough water, then farmers cannot do double cropping in the paddy. Rice production must be ensured in order to sustain food supplies, because rice is a staple food, and Indonesia's current population of 240 million is expected to rise to 300 million by the year 2045. Bali is expected to undergo similar growth. In the past 10 years, paddy areas have decreased by 7 %, but because the production rate has increased by 8 %, rice production in Bali has not changed much (Table 2). In other words, the increase in the rate of production due to technological innovation must keep up with the decline in paddy areas; otherwise, the production volume would fall.

Nevertheless, a sign of production decline has already been seen. A spatial analysis revealed rain pattern changes of 46 % and 54 % in Bali during wet and dry seasons, respectively, between the 1970s and the 2000s (Fig. 2). A soil and climate suitability assessment for paddy production on the basis of a method from FAO shows that the land's suitability for rice production has decreased by 20 % in the past 20 years because of a decrease in precipitation (Prasetya and Novianti 2011). In other words, there is a possibility that rice production will decrease eventually as the productivity lowers. In fact, when the project team interviewed farmers in Bali, some responded that "as there is not enough water, paddy production forced to cut."

The research outcomes reconfirmed the likelihood of climate change in Bali as well as the strong possibility of paddy insecurity following the climate change. The reduction of suitability is mainly due to the decline in precipitation. The north and northeast regions of Bali have been getting drier. Therefore, drought is potentially the number one concern among the weather-related disasters that could harm paddy production.

Table 2 Paddy harvested area, production rate, and production in Bali. In the past 10 years, paddy areas have decreased by 7 %, but because the production rate has increased 8 %, so rice production in Bali is reserved

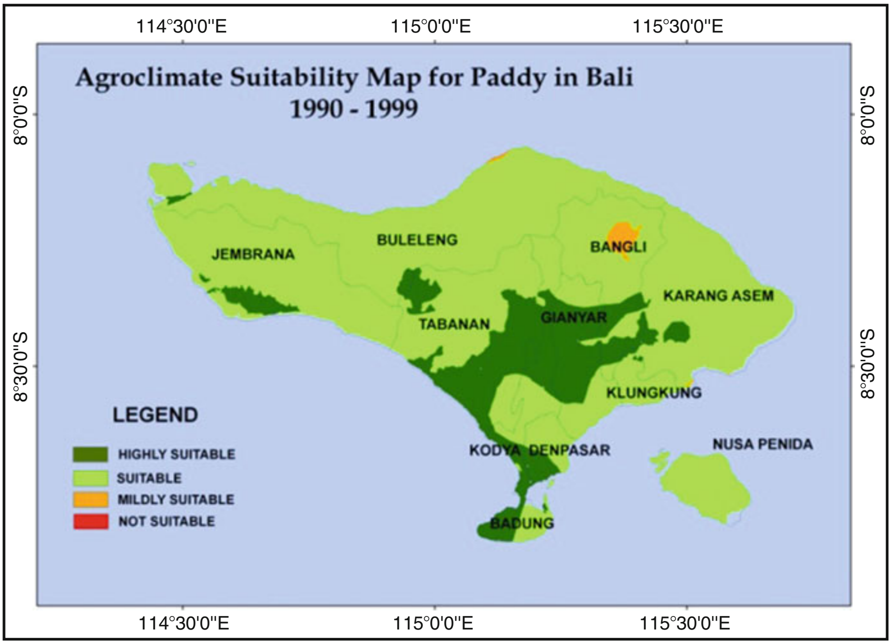
Year	Paddy harvested area (ha)		Production rate (quintal/ha)		Production (ton)
2000	155,049		53.33		826,838
2001	147,942		53.35		789,232
2002	148,025	7%	54.70		809,688
2003	145,294		54.60	8%	793,260
2004	142,663		55.00		788,361
2005	141,577		55.00		785,481
2006	150,557		56.00		840,891
2007	145,030		58.00		839,775
2008	143,999		58.37		840,465

In detail, 1.3 % of Bali's land is highly suitable (S1) for rice production (72,110 ha). Land with middle suitability (S2) covers 31.9 % of Bali (175,650 ha), and land with low suitability (S3) covers 56.9 % of Bali (313,226 ha), while land that is not suitable for paddies (N) covers as much as 9.9 % (54,235 ha). Areas and percentages of land suitability for paddies in each regency are presented in Table 3. For example, "high suitability" areas (S1) cover parts of eastern Tabanan and parts of western Karangasem, and "not suitability" areas (N) cover parts of western Buleleng, parts of northern Tabanan, parts of northern Bangli, parts of northern and eastern Karangasem, and parts of Nusa Penida Island. The soil-climate suitability map in Fig. 2 is used as an exposure map in this vulnerability assessment.

Sensitivity

If no paddies exist in a location where severe drought is expected, then a drought in this location would cause no damage to paddy production, although the drought might cause other problems due to the climatic disaster. Paddy locations as sensitivity are not directly connected to the exposure of climate change; however, in paddy production, these factors cannot be ignored. Sensitivity is spatially determined by the proportion of rice paddy areas in each kecamatan. For example, the paddy fields in the south and central regions, including Gianyar, Tabanan, Badung, and Denpasar, cover more than 20 % of the total area (Fig. 3). Experts on rice paddy production in Bali mentioned that the impact of agriculture on climate needs to be considered seriously for areas with more than 20 % of their land dedicated to agriculture (per com 2012). Therefore, these regions are perceived as areas that will be sensitive to climate impacts on rice production.

As a simple demonstration of the relationship between exposure and sensitivity, the top two maps in Fig. 4 show the change in the soil-climate suitability of paddy production. Areas circled with blue experienced reduced suitability when the precipitation has decreased. The map on the bottom shows the location of the



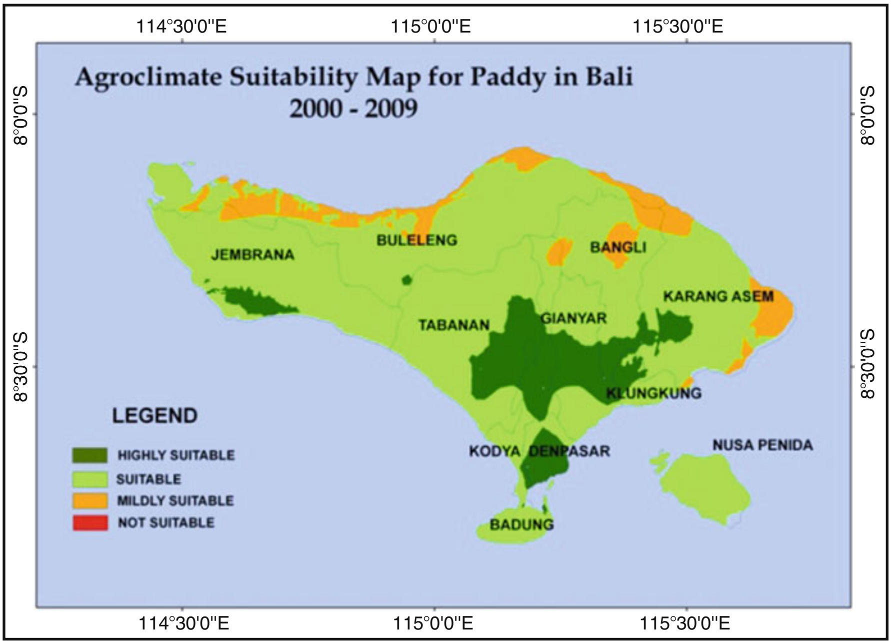


Fig. 2 Reduction of crop suitability: the dark green indicates the suitable areas and orange color indicates the less suitable areas for for rice production in Bali. The areas of dark green has decreased and the area of orange has increased in 20 years

Table 3 Total area and percentage of land suitability for paddy in Bali province

		S1: high suitability		S2: moderate suitability		S3: low suitability		N: not suitable	
	Regency	Total area (Ha)	%	(Ha)	%	(Ha)	%	(Ha)	%
1	Badung	392.6	1.1	10,346.2	27.9	26,046.6	70.4	234.9	0.6
2	Bangli	6.4	0.0	17,853.4	33.6	34,733.5	65.4	505.8	1.0
3	Buleleng			28,768.5	21.9	73,310.2	55.9	29,179.6	22.2
4	Gianyar	40.4	0.1	26,321.4	72.8	9,813.7	27.1		
5	Jembrana			18,675.2	22.7	58,355.0	70.9	5,308.7	6.4
6	Karangasem	1,431.4	1.7	20,943.4	25.5	50,891.2	61.8	9,023.8	11.0
7	Klungkung			726.7	2.5	20,161.2	69.8	7,988.4	27.7
8	Kodya Denpasar			2,767.3	22.9	9,318.9	77.1		
9	Tabanan	5,239.5	6.0	49,248.5	56.6	30,595.5	35.1	1,994.3	2.3

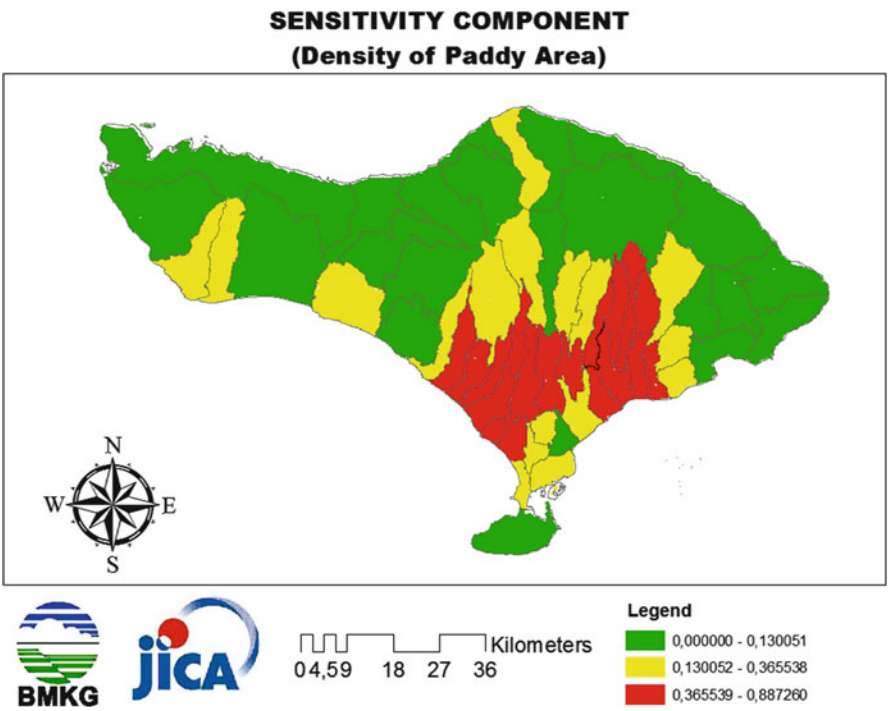


Fig. 3 Proportion paddy areas based on data from BPS-Statistics Indonesia. The red indicates the top 33 percent and green indicates the bottom 33 percent of sensitive areas for rice paddy production in Bali

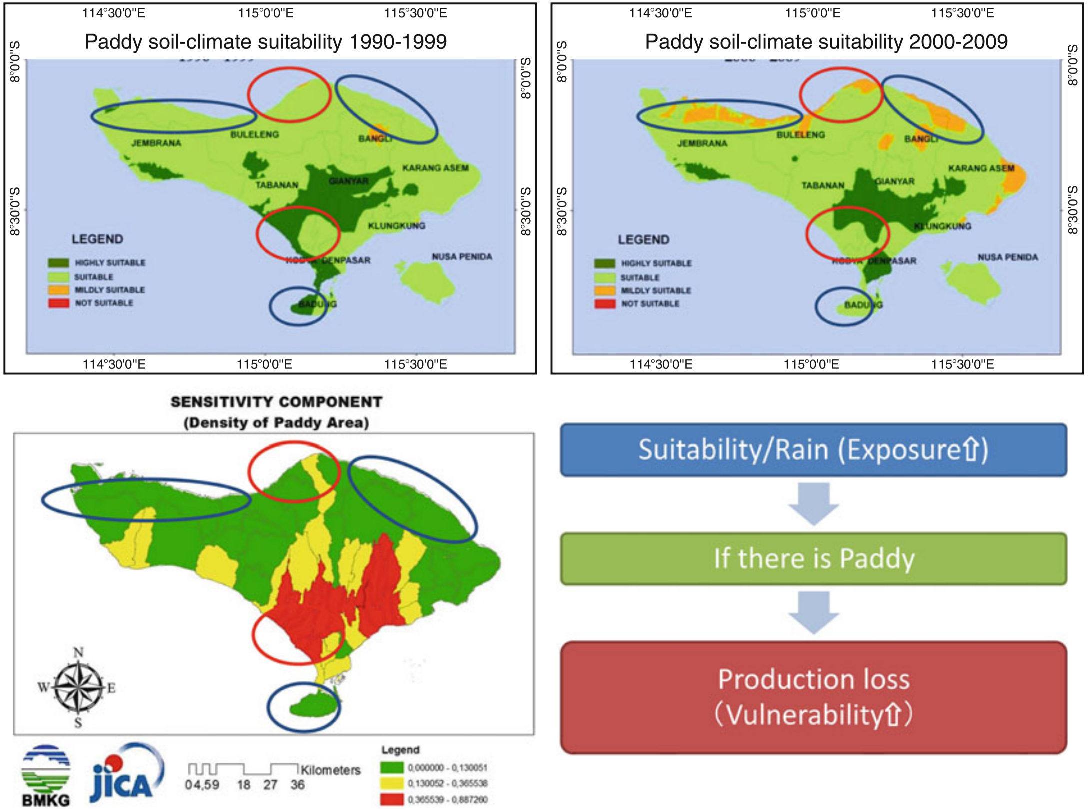


Fig. 4 Demonstration of spatial sensitivity on paddy production. Red circles indicate the areas the suitability has decreased and sensitivity (existing of rice paddy) is high. Blue circles indicate the areas suitability has decreased, but sensitivity is low

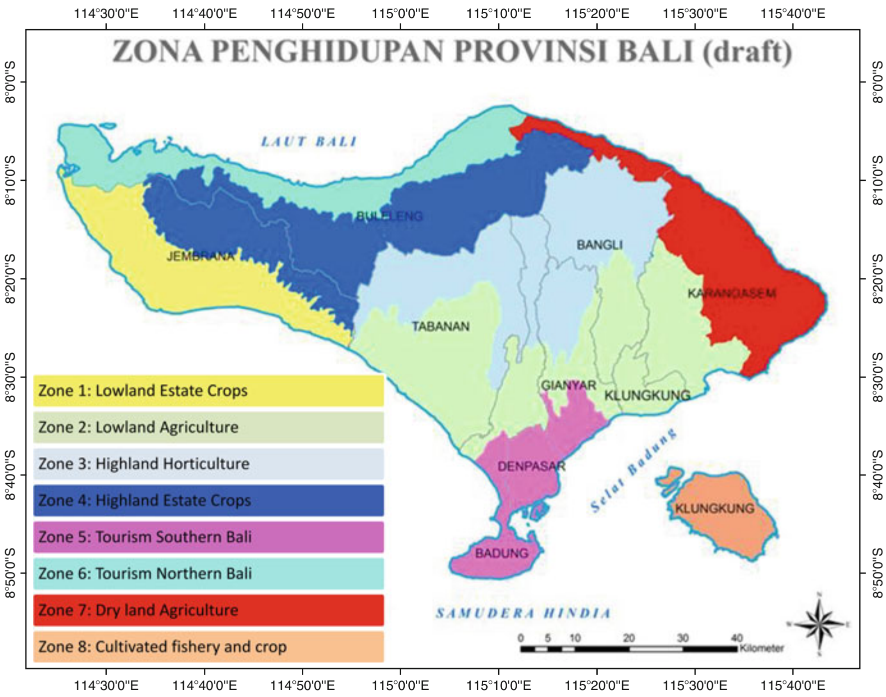


Fig. 5 Livelihood zone map in Bali: Livelihoods are categorized into eight zones based on a means of living through assets, activities, and capabilities

paddy fields. In the areas enclosed by blue circles, there are very few paddies, so the sensitivity in these areas is not high. Therefore, the "vulnerability" of rice production may not necessarily be high. However, the areas with red circles have experienced decreased suitability, and they have many paddy fields. Therefore, vulnerability is higher in these areas.

Adaptive Capacity

To determine adaptive capacity, livelihood zones were first estimated as shown in Fig. 5 after a development workshop and discussion during a stakeholder meeting. The zones explain the overall characteristics of the social activities and geographical features in Bali. The central part is the highland, and the south and southwestern regions are the lowlands. The northeastern region is drier. Typically, the northern and southern regions are more tourism-oriented, and agricultural activities are more important to the rest of the regions.

The survey showed that Zone 1 has the highest rice paddy productivity (74.72 kg/acre) followed by Zones 5, 6, 3, 4, and 2. Zone 7 has the lowest productivity (36.85 kg/acre). The high productivity in Zone 1 may come from the lowland farming. However, Zone 1 and Zone 5 are not paddy-intensive areas. That is, less productive farmers may have already quit rice farming, and only the highly productive farmers may have remained in the two zones. The type of farmers can explain why the survey showed such high productivity in Zones 1 and 5, although rice production is not as popular in these two zones as it is in some other zones. The correlation between farmers' formal education and the productivity of their paddies indicated that formal education does not affect rice paddy productivity. However, farmers with agricultural training produce 54.70 kg/acre, which is 2.65 kg/acre higher than that of farmers who have not had the training. Farmers who use only inorganic fertilizers have higher productivity (60.09 kg/acre) than farmers who use only organic fertilizers (55.21 kg/acre) or farmers who use both organic and nonorganic fertilizers (59.33 kg/acre). In any case, the use of fertilizer seems to affect the productivity of a paddy.

Regression Analysis and Normative Approach for Weighting Value Estimation

The project team is expecting to develop the vulnerability assessment to cover the whole of Indonesia in the future; therefore, scalability was an important consideration during the model construction. The microlevel quantitative data are difficult to access or are likely to be inaccurate in Indonesia. Therefore, the project focused on a model with only mesoscale and macroscale qualitative/categorical data. Regression analyses were carried out with ordinary least square, and the best fitted model is as follows:

$$\begin{aligned}\text{normhvst} = \alpha &+ \beta_1\text{two.cycle} + \beta_2\text{lowland} + \beta_3\text{infari} + \beta_4\text{only.inorganic}\\ &+ \beta_5\text{cooperative} + \beta_6\text{agritrain} + \beta_7\text{owner}\end{aligned}$$

Where:

- normhvst: KGs of unfilled grains per acre under normal conditions
- two.cycle: Dummy variable for cropping two cycles
- lowland: Dummy variable for a lowland paddy field
- infari: Dummy variable for a good variety, i.e., infari 13
- only.inorganic: Dummy variable for using only inorganic fertilizer
- cooperative: Dummy variable for a cooperative in their village
- agritrain: Dummy variable for agricultural training
- owner: Dummy variable for ownership

The coefficients for these variables are shown in Table 4. All coefficients are statistically significant at least to the 99.8 % level. All independent variables are dummy variables; therefore, the results are the same as those of the ANOVA model. Estimates indicate that all seven variables contribute to paddy production. It can also be explained logically the role of each variable in supporting paddy production. Farmers who grow paddy only once a year if their farmlands are not suitable for paddy farming due to lacking water have low productivity, while farmers who grow

Table 4 Coefficients of a paddy production OLS model

	Estimate	Std. error	t value	Pr(>|t|)
(Intercept)	35.15	1.79	19.69	0.00
two.cycle	9.35	1.38	6.75	0.00
lowland	9.27	1.33	6.98	0.00
infari	6.84	2.40	2.85	0.00
only.inorganic	6.11	2.00	3.06	0.00
cooperative	5.11	1.36	3.75	0.00
agritrain	4.14	1.42	2.91	0.00
owner	3.30	1.36	2.43	0.02

paddy three times a year also have low productivity due to decreasing soil nutrient. According to lapse rate, the temperature usually decreases with increasing altitude, and Luh (1991) mentions that the temperature greatly affects grain filling. Low temperature and high humidity during flowering will interfere with a fertilization process resulting in grains becoming empty and causing decreased paddy production, so paddy cultivation in lowland is likely to produce better than that in highland. Inpari13 is a superior variety with potential yield around 8.0 tons/ha; it is resistant to brown plant hopper and some diseases such as blass and "virus kerdil rumput"; grain of inpari 13 does not easily fall off so it can prevent yield loss at harvesting process by 1.34 % and 0.73 % at threshing process (BPTP Indonesia 2010). The advantage of inorganic fertilizers is that nutrients can be tailored to the needs of the plant. Most required nutrients for the growth and yield of the rice crop are N (nitrogen), P (phosphorus), and K (potassium), and these three nutrients are found in inorganic fertilizers. Within a cooperative, farmers share resources and it is easy to access the resources including fertilizer, seed, capital, and insecticide. Through agricultural training, farmers can improve their farming knowledge such as determining the appropriate planting time and choosing the appropriate variety. It is also proved by Suprapto (2010) that a farmer who has been taught by an extension worker has higher production than other farmers who has not been taught. According to Suprapto (2010), there is a correlation between a land ownership and the principal occupation as a farmer, so that those who have the ownership will focus more on running the farm and produce more than other farmers who rent a land.

If none of the variables are available, a farmer produces an average of 35.15 KGs/acre per paddy. The effect is largest with the usage of a two-cycle cropping pattern and is the smallest with the ownership. For example, if a farmer cultivates rice twice per year or owns the paddy field, the farmer can produce an extra 9.35 KGs/acre or 3.30 KGs/acre, respectively. In other words, two-cycle cropping and land ownership, respectively, improve production by 27 % and 9 % (Table 5). The set of percentage improvement was used as the starting point to determine the index for the adaptive capacity for paddy production.

Based on the regression analysis, an index for adaptive capacity was developed normatively via stakeholder meetings and a discussion with experts. In addition to the factors already included in the regression model, other factors might affect

Table 5 Marginal willingness to pay for intercept

(Intercept)	two. cycle	lowland	infari	only. inorganic	cooperative	agritrain	owner
1	0.27	0.26	0.19	0.17	0.15	0.12	0.09

production, including fertilizer types, excess water levels, dams, and land size. These factors are outside of the 10 % significant range; however, they are close enough to be significant to the level and are therefore logical to include.

Using inorganic fertilizer in a limited period can improve the productivity of paddy due to the composition of nutrient contained in the fertilizer. However, Syam'un (2001) states that the continual use of inorganic fertilizers can damage soil's physical properties, resulting a decrease in land productivity. Organic fertilizers provide a low impact on the growth and yield components. This can be overcome by a combination of organic and inorganic fertilizers (Syam and Sariubang 2001). Organic fertilizer can increase the paddy production when combined with a low dose of inorganic fertilizer. The area with an excess water level would ensure the water need of paddy so the plants will grow optimally and have better production. Similarly, the existence of dam will also guarantee the sufficient water for paddy, and water from dam is more stable. All four factors will help the rice production.

Therefore, the project team discussed key stakeholders the possibility of adding these factors. As a result, the project decided to include inorganic and organic mixed fertilizer in the model. The level was decided based on literature reviews and expert opinions (Table 6). Three studies estimating the advantage of the mixed fertilizer compared with inorganic fertilizer were used for the source of the discussion. The productivities rose between 77.3 % and 21 % in these studies, and the stakeholder meeting decided to take the middle value of 50 %. With the additional inorganic and organic mixed fertilizer effect (inorganic. organic), the weighting factor for adaptive capacity was settled as Table 7.

Characteristics of the Most and the Least Productive Subaks

The characteristics of the five most productive and the five least productive subaks were compared to understand the magnitude of the given impacts in extreme situations. Subaks in which less than four farmers were sampled were omitted from this assessment. The five most productive subaks are Baluk, Lanyahan, Berawan Tangi, Pangkung Jajang, and Pangkung Liplip. A total of 29 farmers were sampled from these five subaks, and, on average, they produce rice at 84.97 kg/acre. The five least productive subaks are Datah, Lebah, Penaban, Tegakin, and Pajegan. A total of 35 farmers were sampled from these five subaks, and they produce rice at an average of 30.86 kg/acre.

When the most and least productive subaks are compared (Fig. 6), the difference clearly reflects the factors affecting rice paddy production in the regression model. For example, in the five most productive subaks, 62.86 % of the farmers own their paddy field; in the five least productive subaks, only 34.48 % of farmers own their

Table 6 Literature review for inorganic and organic fertilizers

		Inorganic and organic fertilizer = 4.45 tons/ha	Inorganic and organic fertilizer = 5.28 tons/ha	
		Inorganic fertilizer = 2.51 tons/ha (increasing 77.3 %)	Inorganic fertilizer = 3.52 tons/ha (increasing 50 %)	Grain productivity was enhanced by 21 % and 24 % under CFM and CFS compared to CF, respectively
1.	Resource	IPB (magister course)/seminar paper	BPTP Maluku and South Sulawesi/ Journal Agrivigor	Nanjing Agricultural University, China
2.	Year of research	2008–2009	2004	1987–2005
3.	Place of research	Bogor	Buru Island (Maluku)	Tai Lake Region, China
4.	Organic fertilizer used	Animal manure (10 tons/ha)	Chicken dung (1.5 tons/ha)	Pig manure
				Paddy straw
5.	Inorganic fertilizer used	200 kg urea + 100 kg SP 36 + 100 kg KCl	300 kg urea + 150 SP 36 + 100 kg KCl	Chemical fertilizer
6.	Variety of paddy	Mentik wangi	Gilirang	

Table 7 Weighting factor for adaptive capacity before normalization

(Intercept)	two. cycle	lowland	inorganic. organic	infari	only. inorganic	cooperative	agritrain	owner
1	0.27	0.26	2.6	0.19	0.17	0.15	0.12	0.09

land. In terms of location, all farmers in the five most productive subaks are located in lowlands, whereas only 24.24 % of the farmers are located in the lowlands in the five least productive subaks. 71.42 % of the farmers crop twice in a year in the most productive subaks, and only 6.90 % farmers crop twice in the least productive subaks. Moreover, 80 % and 20 % of the most productive farmers/subaks are, respectively, located in Zones 1 and 3. In contrast, all of the least productive farmers/subaks are located in Zone 7.

The adaptive capacity scores in each livelihood zone are shown in Table 8. The score of adaptive capacity is an index, so meaning arises only through comparisons. On average, Zone 5 has the highest adaptive capacity score followed by Zones 1, 6, 2, 3, 4, and 7. The index for the adaptive capacity of the livelihood zones is mapped in Fig. 5. Generally, the southern and southwestern regions, which have excellent paddy production, have higher adaptive capacity scores, and the central and northeastern regions have lower adaptive capacity scores (Fig. 7).

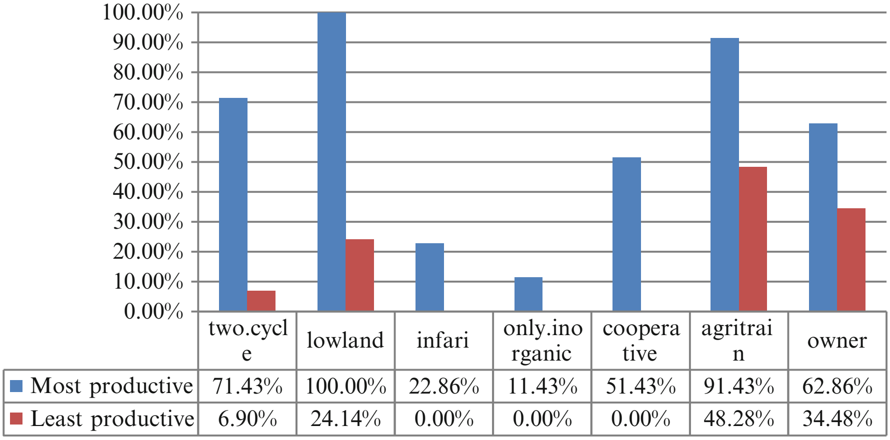


Fig. 6 Comparison between the most and least productive subaks based on seven factors used by the adaptive capacity model

Table 8 Adaptive capacity index for livelihood zones

Livelihood Zones	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	Sample no.
Zone 5	9.529	19.28	24.72	24.91	28.86	37.27	70
Zone 1	3.559	17.05	22.08	21.53	26.32	39.97	68
Zone 6	4.401	13.67	16.97	20.34	29.85	38.26	70
Zone 2	0.2606	13.91	18.78	19.99	27.29	33.13	74
Zone 3	3.559	12.81	18.02	17.54	22.16	31.43	71
Zone 4	0	12.55	16.97	16.74	20.9	28.99	71
Zone 7	0.2606	4.401	9.529	10.76	15.05	26.32	67

Vulnerability Assessment Maps

Several versions of vulnerability maps and indexes were developed. Combining the three components changes the characteristics of the maps and indexes. For example, the maps were developed according to the livelihood zones, so the results are closely related to the actual activities of local people. If the maps had been developed based on political boundaries, such as kabupaten, then they might not have reflected the activities on the ground; nevertheless, political maps can be easier for public officers to interpret and use. Similarly, sensitivity can be defined as an exact rice paddy location or as a density/percentage in a given rice paddy area, such as kabupaten (district) or a livelihood zone. Giving a binomial value to an exact location (1 = exist, 0 = not) produces results that are easier to interpret. For example, one can conclude, "If there is no rice paddy field in the area, then the area will not sustain any damages to rice production." However, it can be harder to get a general overview of each political boundary or zone with binomial values.

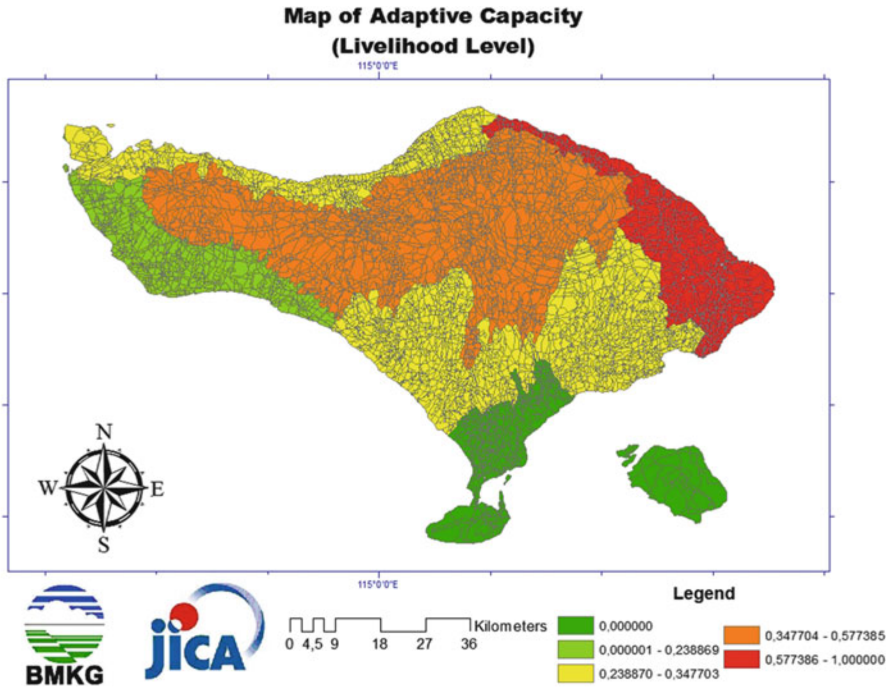


Fig. 7 Adaptive capacity for livelihood zone: green means high adaptive capacity and red means low adaptive capacity. Colors divide the adaptive capacity by 25 percents based on the ranking

As there is no universal agreement on how to make a vulnerability map, the project team verified their maps with stakeholders and local experts. Thus, the vulnerability map is based on a soil-climate suitability map as exposure, a paddy proportion at kecamatan as sensitivity, and rice paddy productivity with socioeconomic factors at livelihood zones as adaptive capacity. The combination was selected according to the needs and purpose of this vulnerability assessment.

After a discussion about the components with local experts, the weighting between the three components were determined as exposure = 0.3, sensitivity = 0.2, and adaptive capacity = 0.5 (Fig. 8). This figure describes all three characteristics of vulnerability in rice paddy production in Bali. The northeastern regions are vulnerable because of lower suitability which comes from drier climate and lower adaptive capacity. The central regions are vulnerable because of lower adaptive capacity. Tabanan is vulnerable because of its high density of paddy areas. The southern region is less vulnerable than Tabanan, because the region enjoys good climatic conditions and high adaptive capacity. Also, comparing the two maps in Fig. 8, there are changes in vulnerabilities in paddy production in Bali. The vulnerability has increased in northwest region and southeast region. The Tabanan area also has some rise in vulnerability.

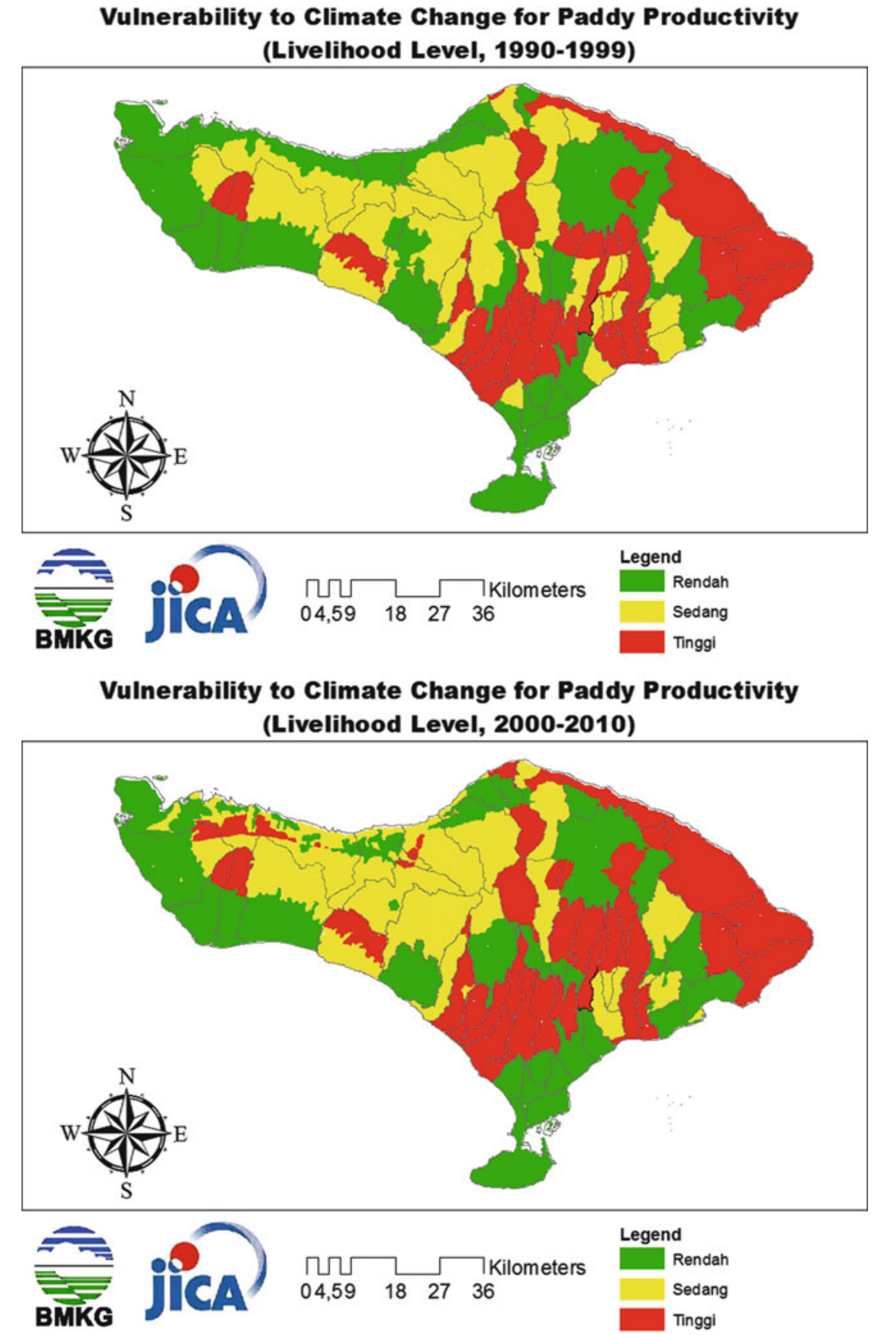


Fig. 8 Vulnerability map for rice paddy production: The *red color* indicates the higher indicate high vulnerability and the *green color* indicates low vulnerability. The *top figure* is the vulnerability based on 1990s climate and the *bottom figure* is based on 2000s climate

Discussion

A vulnerability index gives the overall picture of a vulnerability assessment. However, a vulnerability index will not give policymakers an entry point to plan adaptation measures, because they do not provide enough details about each component's unique characteristics. It is necessary to check the index of each component to understand the starting points for policy actions. An exposure index shows potential disasters, a sensitivity index shows the existence of exposure units, and an adaptive capacity index shows where abilities to handle the potential disasters are weak. For example, if policymakers need to know the location where potential disasters will happen, they need to check an exposure index and map. However, they also need to see a sensitivity map to check whether disaster-prone area has an exposure unit, and they must consult an adaptive capacity map to verify whether the exposure unit and related livelihood and stakeholders have enough adaptive capacities. The point is that checking each component is more practical than checking the weight of three components. Therefore, normative and abstract weighting between the three components is enough when a vulnerability assessment is implemented.

For example, the vulnerability map indicates high vulnerability in the northeastern region, and this vulnerability exists because of high exposure and low adaptive capacity. In this case, it is important to have proper policy actions to support the rice farmers in this region. Agricultural extension is one of policy tools that is used by a local government to encourage the development of agriculture, where agriculture extension workers have a significant role in helping farmers offering the information related to climate change and climate impacts and teaching new technologies to cope with the climatic impacts. It can be done among others through agricultural training. Our preliminary results show that a farmer who has received training from an agricultural extension worker is likely to increase their rice paddy production by 4 kg per acre, which is a 12 % gain in productivity. Strengthening the current extension system is one approach. If that is difficult due to the change in institution and management, other players such as universities, agrobusinesses, NGOs, and farmers' organizations may need to play a greater role. BMKG's climate field school is a successful example. Another way to strengthen the adaptive capacity is supporting the cooperative that can help the people to prepare for the high exposure in the region, because adaptive capacity is low there. Tabanan is a vulnerable area, but that is mainly due to high sensitivity. Therefore, policy actions will be different in Tabanan than they will be for the northeastern region. In Tabanan, the gravest concern will be catastrophic disasters and diseases, because the majority of land and farmers are engaged with rice paddy production. Therefore, the support for Tabanan can be ad hoc. For example, when a heavy drought is likely to come, the local authority may provide drought-resilient seeds and fertilizers to the farmers in Tabanan. Both climate and adaptive capacity are generally in good condition in Tabanan, so policymakers might not need to focus on training and cooperatives in this region.

If an area's productivity is low because of low adaptive capacity, policies on agricultural training and cooperatives can help adaptive capacity significantly and directly, and eventually, capacity development works will raise rice productivity. For adaptation planning based on a vulnerability assessment, the information from the three components is likely to be more useful than the final vulnerability value. Having said that, the vulnerability value is still useful for gaining a big picture of a region or a sector, but, to plan a policy, it is necessary to get information from the component level.

Moreover, Fig. 8 shows there are some changes in the vulnerability in the two periods between 1990s and 2000s. The assessment did not change sensitivity and adaptive capacity; therefore, the changes are all based on exposure such as climatic factors. Some parts of Bali have gotten drier, if the vulnerability increased. The final vulnerability map indicated not only climate change but also a vulnerability change in rice paddy production in Bali.

Perceptions of Climate Change and Impacts

Correlation and causation have to be carefully distinguished in the vulnerability assessment. In the survey result of adaptive capacity, farmers who do not perceive extreme events like flooding and their effects on paddy qualities and quantities as related to climate change have better production than other farmers, with a 95 % statistical significance. For example, farmers who do not consider the adverse effects of climate change generally produce about 5 kg of rice paddy per acre more than farmers who consider the effects. However, this does not mean that "no perception of climate change" results in better rice paddy production. Instead, these farmers already have better rice paddy production; therefore, they are likely to "not care about climate change." In other words, "good rice paddy production" can make these farmers ignorant of climate change and its potential impact. Thus, the ignorance factor should not be included to set up a paddy production function or vulnerability factors, because the causation from these factors to paddy production cannot be explained.

The climate-ignorant farmers enjoy good productivity now, but if impacts from climate change worsen and farmers continue to ignore them, then these farmers may not cope well with the adverse effects of climate change in the future. This is the definition of vulnerability from IPCC. The farmers who do not perceive climate change and its potential impact can be more vulnerable than other farmers, as the actual paddy qualities and quantities are affected by the change in climate. Moreover, the climate change assessment in the current project suggests that climate change seems to be happening in Bali. Ignoring these changes may affect future rice paddy production significantly for these uninformed farmers.

Roles of Agencies to Disseminate Climatic Information

Results show that farmers who have received training from an agricultural extension worker are likely to increase their rice paddy production by 4 kg per acre, which is a 12 % gain in productivity. Centennial Group International (2012) mentioned that the agricultural extension worker system has been weakened due to institutional and management changes, such as funding responsibility and provision of services. Therefore, at the present time, the agricultural extension system is not uniform. For example, only 2,560 extension workers, or 6 % of the total number, hold bachelor's degrees, and the rest hold lower qualifications. The agricultural extension system has a significant role to play in rice paddy production, and if the system declines, then productivity may also decline.

Conclusion

This report demonstrated how to develop a vulnerability index and maps with a quantitative and normative qualitative approach. Exposure as a potential disaster was presented by a soil-climate suitability map, and the map indicates climate change in Bali. Sensitivity was displayed as rice paddy production. Adaptive capacity was estimated by a regression model of social factors related to rice paddy production. The final map successfully indicated the regions that are vulnerable to reductions in rice paddy production due to climate change, which are, namely, the northeast, central west, and Tabanan regions.

The results of this assessment can be used for policy implementation, such as agricultural training. Since agricultural training will improve the production of rice more than 4 kg per acre, policymakers can improve the adaptive capacity of rice farmers by reinforcing agricultural training programs, which have been degrading. In addition, the results of the adaptive capacity assessment will be used to assess the vulnerability of rice paddy production. This assessment requires two more components: exposure to climatic impacts and sensitivity to such impacts. To utilize the vulnerability assessment in the future, continuous assessment and engagement with stakeholders will be necessary. Usually, less-capable farmers should receive higher attention in the vulnerability assessment, because the results indicate that they are vulnerable to the current climate and that the adverse effects of climate change will hit them harder. It is important to provide correct climate information to farmers, and developing vulnerability maps that are matched to the needs of users will help to support farmers and policymakers by providing comprehensive vulnerability information.

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Climate, Climate Risk, and Food Security in Sri Lanka: The Need for Strengthening Adaptation Strategies

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Abstract

Climate is one of the main determinants of agricultural productivity in Sri Lanka. Of the major climatic parameters, temperature, rainfall, and humidity are of special significance, as these cause a substantial impact on the agricultural productivity of the country. Consequently, farming systems and agronomic practices in most agricultural regions of Sri Lanka have evolved in close harmony with the prevailing climatic conditions of respective climatic regions of the island. The overwhelming scientific research has provided evidence of two general trends in Sri Lankan climate, i.e., increasing ambient temperatures resulting in more heat stress, and more frequent and severe occurrence of extreme rainfall anomalies such as droughts and floods. Both of these conditions strongly affect the crop and animal production and thus the food security in the country. The National Climate Change Policy of Sri Lanka, which was adopted in 2012, clearly endorses the need of appropriate adaptation strategies to reduce the impacts on crop and animal production so as to ensure national-level food security. While some of the strategies and actions have already been implemented as an effort to address the emerging negative impacts of climate change, scope still exists for new entry points for adaptation with a view to reduce the climate vulnerability of the agricultural sector in Sri Lanka while increasing the resilience of the entire community. One example of these actions is the development of seasonal climate forecasts that could assist farmers, business across the value chain, and the policy makers to develop improved climate risk management strategies leading to ensuring food security.

This chapter provides a comprehensive overview of the climate and climate-related risks faced by the agriculture sector of Sri Lanka and highlights the need to strengthen adaptation options to ensure national-level food security.

Keywords
Climate risks • Crops and animals • Adaptation • Food security • Sri Lanka

Introduction

Sri Lanka is an island in the Indian Ocean located at the tip of the Indian subcontinent. The country has a total land area of 65,610 km^2 including 2,905 km^2 of inland water bodies. The maximum width from east to west is 240 km and the length in north-south direction is 435 km. Sri Lanka is located between 5°55–9°5′ North latitudes and 79°42–81°53′ East longitudes and hence has an equatorial climate. Extensive faulting and erosion over time have produced a wide range of topographical features with three distinguishable elevation zones within the island: the Central Highlands, the plains, and the coastal belt. In the south-central part of Sri Lanka, the rugged Central Highlands spans around 65 km in north-south direction with peak elevation at 2,524 m. The Central Highlands is the hydrological heart of the country as almost all major perennial rivers originate here, spreading radially from the highlands to the coast. Most of the island's surface consists of plains between 30 and 200 m above sea level. In the southwest, ridges and valleys rise gradually to merge with the Central Highlands, giving a dissected appearance to the plain. A coastal belt about 30 m above sea level consists of scenic sandy beaches indented by bays and lagoons.

Despite its relatively small extent, Sri Lankan landmass exemplifies a variety of climatic conditions. There are four important geographical and topographical features in Sri Lanka, which considerably influence the climate over the island, in particular the rainfall regime. The first is the fact that Sri Lanka is a small island situated in the warm tropical Indian Ocean with associated warm, humid air. The second is its proximity to the equator, which results in solar radiation rarely being a limitation to crop growth under general weather conditions of the island. The third is the existence of a large mass of hills at the center of the island, which is perpendicular to two approaching moisture-laden monsoon wind streams (the southwest monsoon in the middle of the calendar year and the northeast monsoon towards the end of the year). The fourth factor is the presence of a vast landmass of the Indian subcontinent to the immediate north and northwest of Sri Lanka, which has a large effect in driving the monsoon. These four factors directly or indirectly influence the rainfall regime of the island. In general, the climate of Sri Lanka is considered as tropical monsoonal with a marked seasonal variation of rainfall. Of the major climatic parameters, temperature, rainfall, humidity, and evaporation are of special significance to Sri Lankan agriculture, impacting substantially on the agricultural productivity of the country.

This chapter focuses on the general climate of Sri Lanka, climate-induced risk factors that influence agriculture production (considering both crop and animal production), and the relationship of these to the food security of the nation.

Rainfall

Rainfall in Sri Lanka has multiple origins. Monsoonal and convectional rainfall, and the formation of synoptic weather especially in the Bay of Bengal, account for the majority of the annual rainfall. The average annual rainfall of the island (Fig. 1) varies from about 900 mm at the southeastern part of the Dry Zone (*Maha Lewaya* at Hambantota) to over 5,500 mm on the southwestern slopes of the Central Highlands (Kenilworth Estate at Ginigathhena) (Punyawardena et al. 2013a).

The rainfall experienced during a 12-month period in Sri Lanka can be characterized into four rainfall seasons, namely, first inter-monsoon (March–April; FIM), southwest monsoon (May–September; SWM), second inter-monsoon (October–November; SIM), and northeast monsoon (December–February; NEM).

First Inter-monsoon Season (March–April)

Warm, humid, and uncomfortable conditions, with thunderstorm-type rain, particularly during the afternoon or evening, are the typical weather conditions during the first inter-monsoon (FIM) season. The distribution of rainfall during this period shows that the entire Southwestern sector of the hill country receives 250 mm of rainfall, with some localized areas on the Southwestern slopes experiencing rainfall in excess of 700 mm (e.g., 771 mm at the Keeragala Estate). Over most part of the island, the amount of rainfall varies between 100 and 250 mm, the notable exception being the Jaffna Peninsula in the Northern Province, which has lower rainfall in the FIM season (e.g., Jaffna, 78 mm; Elephant Pass, 83 mm; Fig. 2).

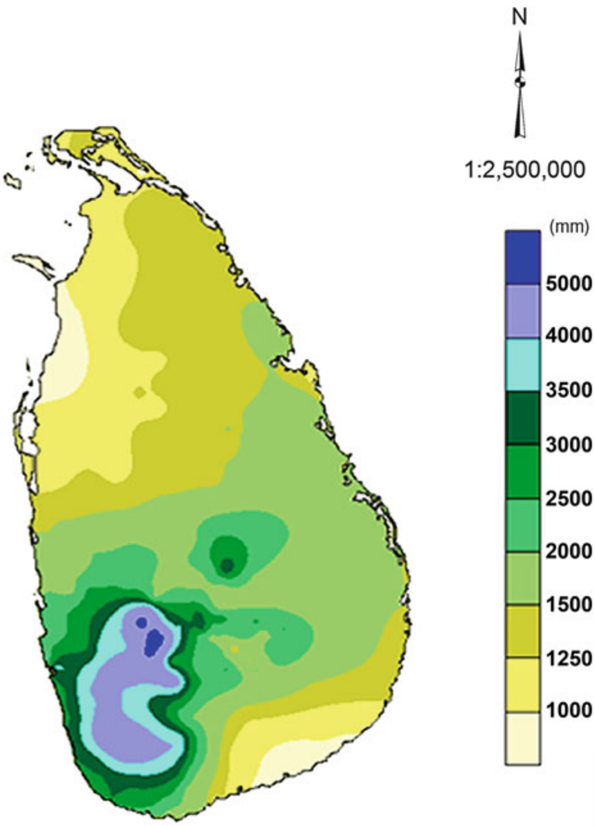
Southwest Monsoon Season (May–September)

Windy weather during the southwest monsoon (SWM) results in lower temperatures than those prevailed during the FIM season. The SWM rain totals vary from about 100 mm to over 3,000 mm (Fig. 3). The highest rainfall is received in the mid-elevations of the Western slopes (e.g., Ginigathhena, 3,267 mm; Watawala, 3,252 mm; Norton, 3,121 mm). Rainfall decreases rapidly from these maximum regions toward the higher elevation, as in Nuwara Eliya, it drops to 853 mm. The lowest rainfall is recorded from the Northern and Southeastern regions.

Second Inter-monsoon Season (October–November)

The second inter-monsoon (SIM) season is characterized by convective weather systems that typically generate thunderstorm-type of rain, particularly during the afternoon or evening (Fig. 4). However, unlike in the FIM season, the influence of weather systems such as low-level atmospheric disturbances, depressions, and

Fig. 1 Spatial distribution of the average annual rainfall in Sri Lanka (Source: Department of Meteorology, Sri Lanka)



cyclonic storms in the Bay of Bengal are common during this period. Under such conditions, the whole country can experience strong winds with a widespread, intense rain, which could lead to floods and landslides. The SIM period of October–November experiences the most evenly geographic distribution of rainfall in Sri Lanka. Almost the entire island receives in excess of 400 mm of rain during this season, with Southwestern slopes receiving higher rainfall in the range 750–1,200 mm (e.g., Weweltalawa, 1,219 mm).

Northeast Monsoon Season (December–February)

The dry and cold wind blowing from the Indian landmass will result in a comparatively cool but dry weather over many parts of Sri Lanka during the northeast monsoon (NEM) season, creating a pleasant and comfortable weather except for some rather cold morning hours in January. Cloud-free skies in January often provide days full of sunshine and pleasant and cool nights. During the NEM period, the highest rainfall amounts are recorded in the Eastern slopes of the Knuckles Range of the central hills (Fig. 5). The maximum rainfall is experienced at the

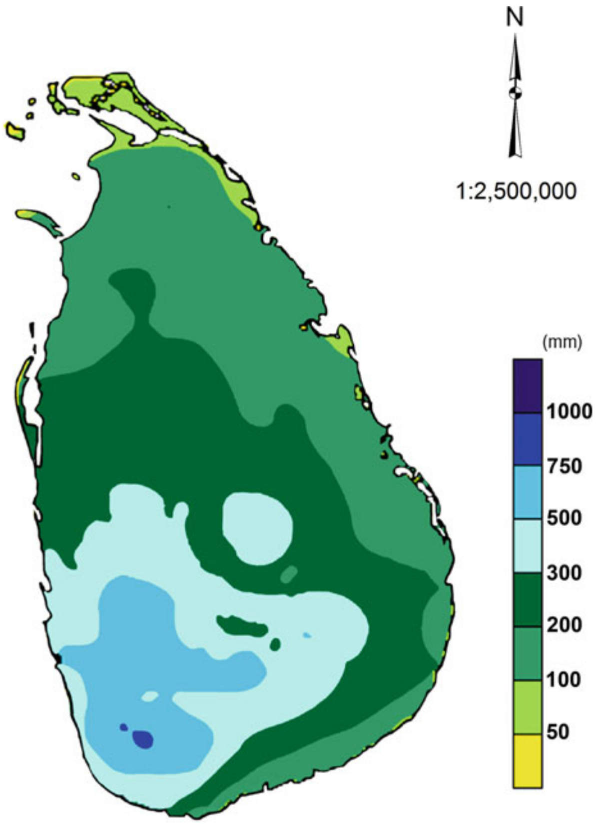


Fig. 2 Spatial distribution of the average rainfall in the first inter-monsoon in Sri Lanka (Source: Department of Meteorology, Sri Lanka)

Koboneela estate (1,281 mm), and the minimum is in the Western coastal area around Puttalam (e.g., Chilaw, 177 mm) during this period. There can be high interannual variability.

As depicted in Figs. 2, 3, 4, and 5, the four rainfall seasons do not bring homogeneous rainfall regimes over the whole island, thus leading to a high agro-ecological diversity in the country despite its relatively small extent. Out of the four rainfall seasons, two consecutive rainy seasons make up the major growing seasons of Sri Lanka, namely, *Yala* and *Maha* seasons. Generally, *Yala* season is the combination of FIM and SWM rains. As SWM rains are the highest over the country's Southwestern sector, the length (effectiveness) of this season in the rest of the country is generally confined only to 2 months (mid-March to early May), and hence, the *Yala* season is considered as the minor growing season of the country. The major growing season of the island, i.e., *Maha* season, begins with the arrival of SIM rains in October and continues up to late January/February with the NEM rains. Being mainly convective in nature, rains during the two inter-monsoon periods are usually associated with thunder and lightning along with short-duration high-intensity rains, especially during the FIM period.

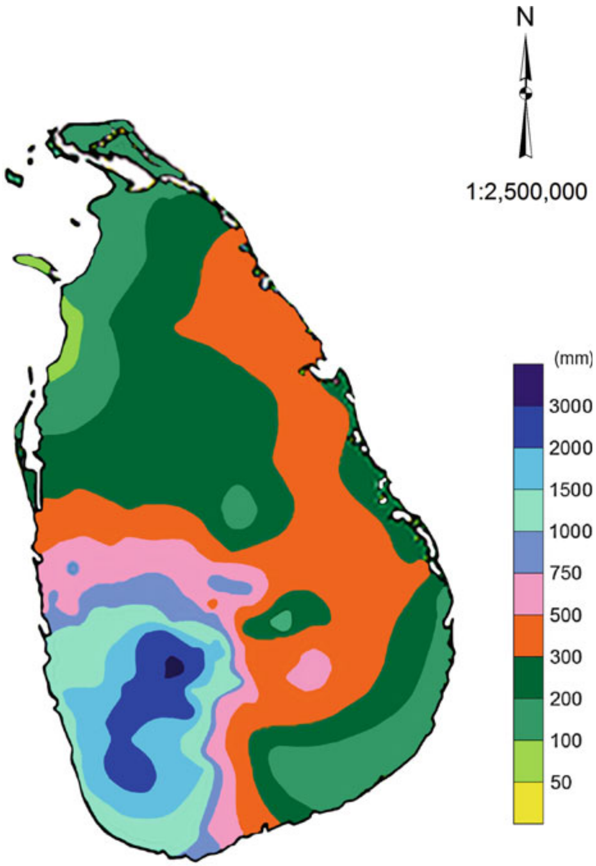
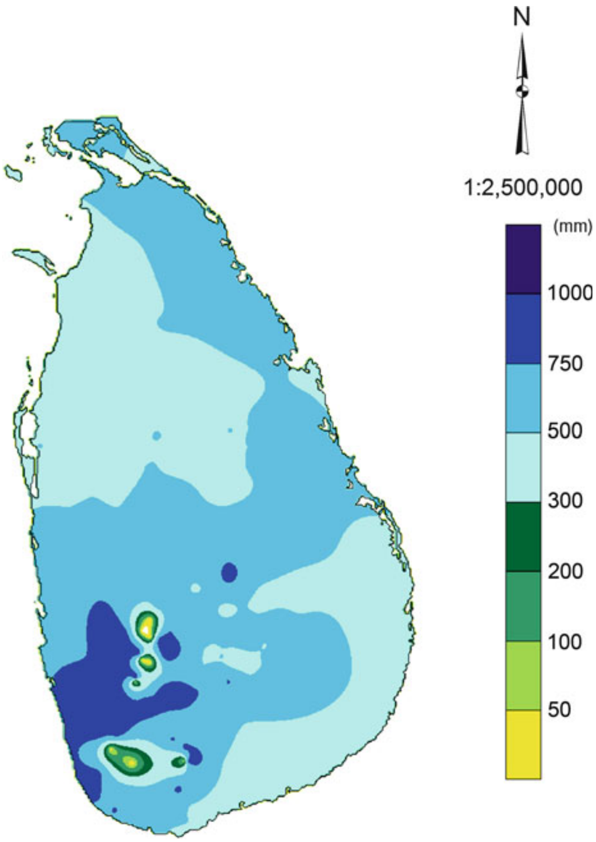


Fig. 3 Spatial distribution of the average rainfall in the southwest monsoon in Sri Lanka (Source: Department of Meteorology, Sri Lanka)

Temperature

The mean annual temperature in Sri Lanka manifests largely homogeneous temperatures in the lowlands and rapidly decreasing temperatures in the highlands. In the lowlands, up to an altitude of 100–150 m, the mean annual average temperature is 27 °C. In the highlands, the temperature falls quickly as the altitude increases. The mean annual temperature of Nuwara Eliya at an altitude of about 1,800 m is 15 °C. However, during the period of January to mid-February, the diurnal temperature variation around Nuwara Eliya is large, and thus, ground frost can be observed for about 3–7 days early in the mornings or nights when the temperature closer to the ground falls below the freezing point. However, during the period of May to September, if the westerly winds are strong, the leeward area in the east of the Central Highlands and the relatively flat terrain extending to the east coast experience warm, dry, and gusty winds. Such foehn-like winds are locally known as the *Kachchan* or *Yal-hulang*. In foehn conditions, the relative humidity

Fig. 4 Spatial distribution of the average in rainfall in the second inter-monsoon in Sri Lanka (Source: Department of Meteorology, Sri Lanka)



may fall to less than 50 %, causing vegetation and soil to dry out with possible bushfire disasters in Badulla and Moneragala districts. The coldest month with respect to the mean monthly temperature is January and the warmest months are April and August.

Relative Humidity

The relative humidity (RH) in Sri Lanka generally ranges from 70–90 % during mornings to 55–80 % during late afternoons depending on the geographical location. Relatively low humidity values (from 40–60 %) are reported in dry lowlands during June to August where the foehn-like wind (*Kachchan* wind) is often prominent. Comparatively high humidity condition that prevails during winter months (December to January) is one of the predisposing factors for plant disease outbreaks during the *Maha* season.

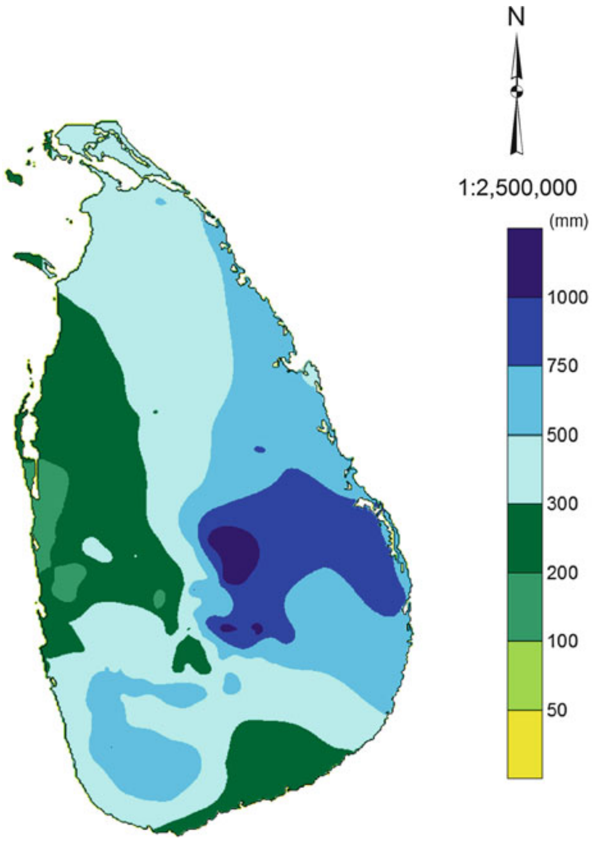


Fig. 5 Spatial distribution of the average rainfall in the northeast monsoon in Sri Lanka (Source: Department of Meteorology, Sri Lanka)

Evaporation

During the *Yala* season, pan evaporation is likely to range between 3 and 8 mm per day depending on geographical region. Higher values over 7 mm per day are often experienced in the dry lowland areas during this period. Meanwhile, a range of 2–5 mm per day is generally observed during the *Maha* season across different localities of the island.

Climatic Zones of Sri Lanka

Sri Lanka has traditionally been generalized into three climatic zones, namely, "Wet Zone" in the Southwestern region including central hill country, "Dry Zone" covering predominantly the Northern and Eastern parts of the country, and "Intermediate Zone," skirting the central hills except in the South and the West (Fig. 6).

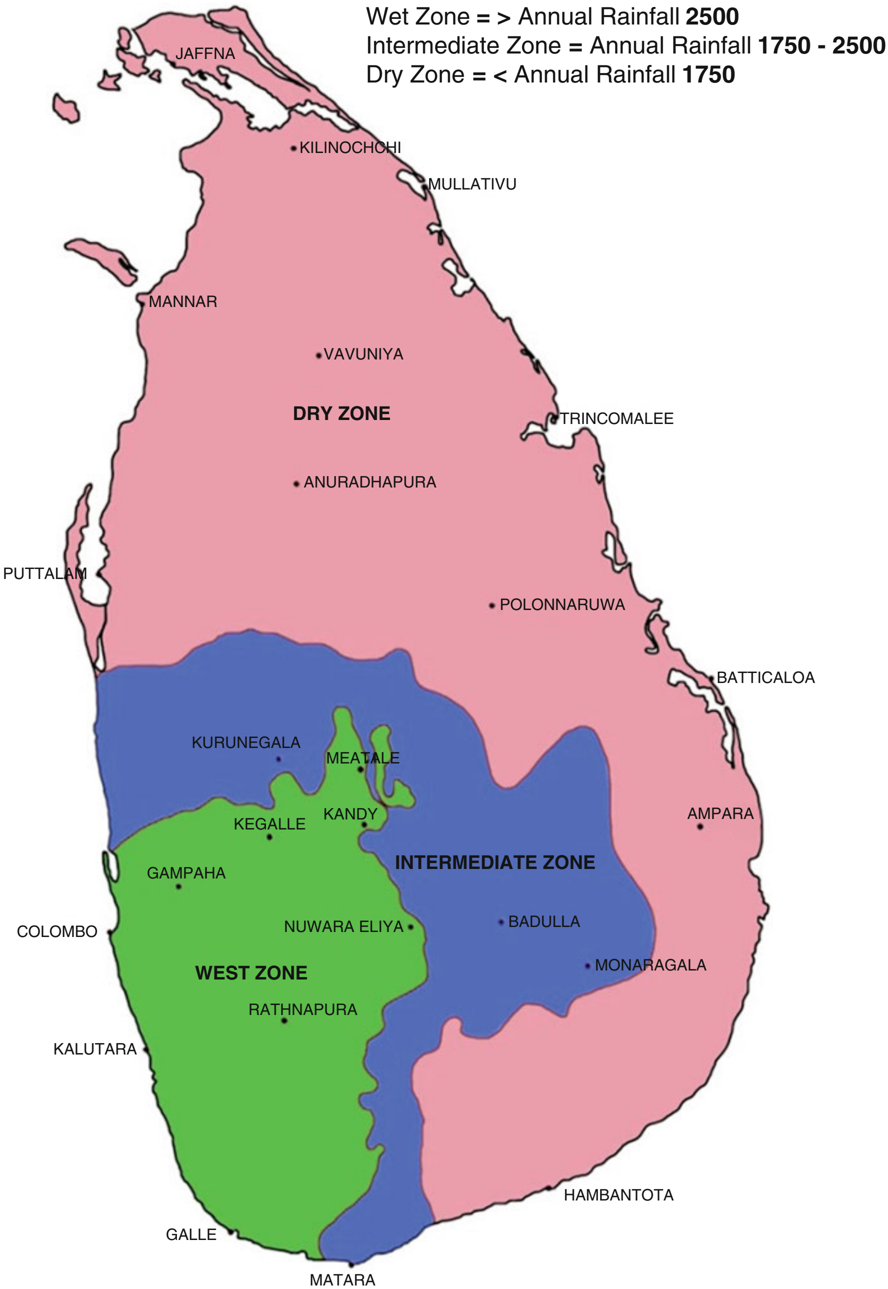


Fig. 6 Climate zones of Sri Lanka (Source: Punyawardena 2007)

In differentiating these three climatic zones, annual rainfall, contribution of southwest monsoon rains, soil type, land use, and vegetation have been widely used (Punyawardena 2007). The Wet Zone receives a relatively high mean annual rainfall over 2,500 mm without pronounced dry periods. The Dry Zone receives a mean annual rainfall of less than 1,750 mm with a distinct dry season from May to September. The Intermediate Zone receives a mean annual rainfall between 1,750 and 2,500 mm with a short and less prominent dry season. Sri Lanka has been further divided into 46 agroecological regions (Punyawardena 2007) that take into account the monthly rainfall amount (at 75 % probability) and distribution in addition to the parameters considered for identifying climate zones.

Climate Change in Sri Lanka

Sri Lanka possesses a long series of historical climatic data, especially rainfall and temperature records, which started from the 1860s in some locations. A recent analysis of these data has shown that the country's average temperature is significantly increasing at a rate of 0.01–0.03 °C per year (Fernando and Chandrapala 1995; Nissanka et al. 2011; Premalal and Punyawardena 2013). The increase is more pronounced in nighttime minimum temperature than that of the daytime maximum temperature (Marambe et al. 2012). However, due to high interannual variability, there are no discernible significant trends in seasonal and annual rainfall (Nissanka et al. 2011; Marambe et al. 2012), except a few locations among over 400 rain gauging stations of the country as has been found in many other locations across the globe. The same is true in terms of variability of cumulative and seasonal rainfall. However, it was evident that variability of seasonal rainfall during the most recent decade (2001–2010) has increased compared to the previous decade (1991–2000) in most places of the island across all three climatic zones with occurrence of more frequent drought and flood conditions.

A recent study focused on the occurrence of extreme positive rainfall anomalies in the central hills of the country has shown that in contrary to common belief, there is no significant increase of "heavy and very heavy" events in the region (daily rainfall values that exceeded the 95th and 99th percentile values, respectively, in each station from 1961 to 2010), but an apparent increase of such events during the period of 2006–2010 has been evident (Punyawardena and Premalal 2013). The temperature and rainfall projections in Sri Lanka under A2 and B2 scenarios using ECHAM4 general circulation model (GCM) for downscaling have revealed that the average annual temperature of Sri Lanka will increase with a range of 2.5–4.5 °C by the year 2080 under the A2 scenario and with a possible average annual temperature increase of 2.5–3.25 °C under the B2 scenario (Punyawardena et al. 2013a). Both these projections are analogous with the IPCC global projections of temperature changes at the turn of the century. In terms of the future rainfall climatology of Sri Lanka, projections with A2 scenario have revealed that Dry Zone will become drier while Wet and Intermediate Zones may become wetter than at present. In recent studies carried out in Sri Lanka, Marambe et al. (2012) and

Premalal and Punyawardena (2013) reported that climate change may be manifesting in changed conditions of the monsoons, with change in the date of onset and high variability, resulting in drier dry areas and wetter wet areas. Meanwhile, the B2 scenario uncovers a relatively complex situation of both Dry Zone and the Central Highlands of Sri Lanka to become drier than today as time progresses while the wetter parts of Sri Lanka to become further wet but at a lesser rate compared to the A2 scenario (Punyawardena et al. 2013b).

Vulnerability of Sri Lanka to Climate Change

Climate change is a cross-cutting issue and it is increasingly recognized as a necessary component of development-oriented decision-making process. In order for development investments to become resilient to anticipated climate change, it is important to understand the nature of vulnerability from a subnational perspective and reflect this variance in development strategies that are formulated at different administrative levels such as province, district, and divisional secretariat (DS) levels.

Punyawardena et al. (2013a), using 22 physical and socioeconomic parameters, which directly related to all three components of climate change vulnerability, namely, exposure, sensitivity, and adaptive capacity, have revealed that spatial variations of vulnerability of Sri Lanka to climate change varies according to socioeconomic, environmental, and institutional conditions of respective administrative districts in ways that do not necessarily follow the most exposed and geographically sensitive districts (Fig. 7).

The urban areas in the low-country Wet Zone except Ratnapura district are by far the least vulnerable to climate change in Sri Lanka, despite some exposure to climatic hazards such as floods. Communities in the Northern Province (excluding Jaffna Peninsula) and Puttalam and Ratnapura districts are confronted with very high degree of vulnerability due to high exposure, high sensitivity of livelihoods, and lower socioeconomic development. The major rice-producing districts of the island, namely, Anuradhapura, Polonnaruwa, Batticaloa, Hambantota, Monaragala, and Kurunegala (Trincomalee and Ampara in the Eastern Province are the exceptions), are located in the Dry and Intermediate Zones and are highly vulnerable to climate change. The mountainous districts of the Western and Eastern flanks of the central hills of Sri Lanka, namely, Kandy, Matale, Nuwara Eliya, and Badulla, along with Trincomalee and Ampara districts in the Eastern Province, show a moderate degree of vulnerability to climate change.

Food Security in Sri Lanka: Present Status

Food security (FAO 2009) in Sri Lanka is determined by several factors including diverse food systems and farming systems. Food systems in Sri Lanka are affected to different degrees by natural disasters induced by the climate change with a larger

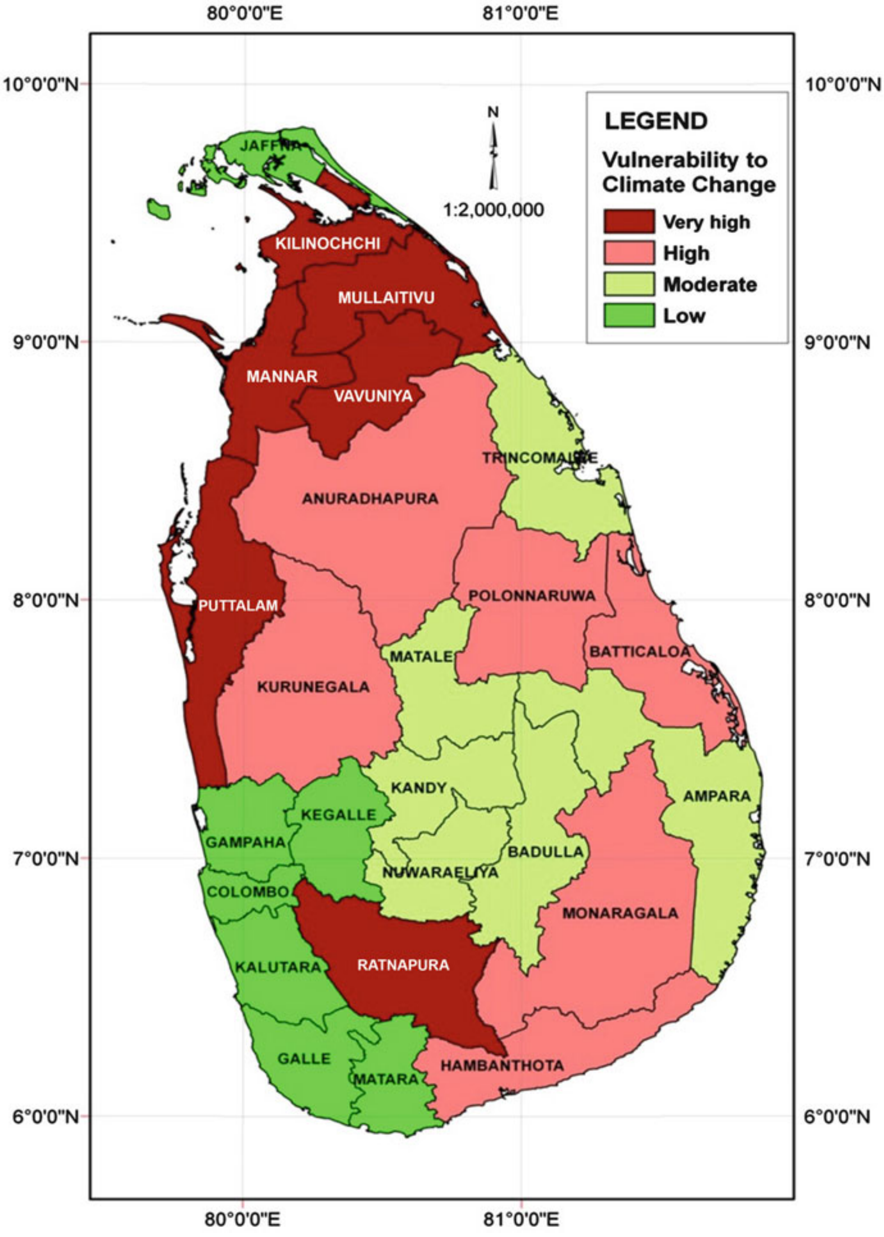


Fig. 7 Regional vulnerability of Sri Lanka to climate change (Source: Punyawardena et al. 2013a)

spatial variation. Sri Lanka's traditional farming systems have developed over hundreds of years with farmers managing production systems in the agroecological regions to best suit local environmental conditions. This has led to a rich agro-biodiversity in the island in terms food crops such as rice, cereals, pulses, vegetables, root and tuber crops, spices, and fruits. Changes in climatic conditions may, however, change the conditions that define the agroecological regions and reduce the productivity of crops and animals that are adapted to them. Conversely, they may allow new options in some areas. Currently, more than two million hectares are under some form of agriculture in Sri Lanka. However, much of the agricultural lands are located in the water-deficient Dry Zone where increased productivity of crops (other than paddy) depends almost entirely on rainfall.

In terms of food security, self-sufficiency in rice production has been the major strategy of agricultural policy since Sri Lanka gained independence in 1948. This has supported generation of employment and elimination of rural poverty. Sri Lanka reached the stated goal of self-sufficiency in rice in the year 2010 mainly due to the investments on research and development. The rice research outputs in Sri Lanka in the last half century further corroborate this contention in that on an average, for every 1 % increase in rice research investment, rice production increased by 0.37 % with an internal rate of return of 174 % in a tariff-protected regime and a benefit/cost ratio of over 2,300 (Niranjan 2004).

Poverty, climate change, decreasing arable agricultural land, and increasing population pressure are the main issues that render achieving the national-level food and nutrition security more challenging in Sri Lanka (Marambe 2012; Weerakoon 2013). The World Food Programme (2011) reported that out of the total population of Sri Lanka, 12 % are severely food insecure, of which 82 % are in the Northern and Eastern Provinces. Extreme climate events, such as the severe drought that prevailed over a period of 5–6 months in the year 2012, will provide its own challenges to food security in the near future. The Global Food Security Index 2013 (www.eiu.com/public/topical_report.aspx?campaignid=FoodSecurity2013) has ranked Sri Lanka 60th out of 107 countries. This index assists to identify and compare the core issues of food affordability, availability, access, and quality across countries.

Main Climate Risks for Food Security in Sri Lanka

The climate changes in recent decades in the forms of natural calamities like drought, flood, cyclone, accelerated land degradation, and sea-level rise pose serious threats to agricultural productivity and food security. Additional pressure coming from ever-increasing population, poor terms of trade, weak infrastructure, and limited access to modern technology and market restrict the options available for people to cope with the negative consequences of climate change. The main food-related agricultural products in Sri Lanka are crops such as rice and other field crops, fruits and vegetables, and animal products such as milk, meat, eggs, and fish. Sri Lanka has experienced frequent natural disasters in the wake of drought, flood, landslide, and cyclone events threatening its agricultural production. Coastal hazards such as coastal erosion and salinity intrusion to soils and aquifers are a common feature that affects agricultural production, especially in the drier parts along the Eastern coast of the country. Decreasing arable agricultural land, together with increasing population, renders these challenges more difficult to tackle. In Sri Lanka, most crops, e.g., coarse grains, legumes, vegetables, and potato, are likely to be adversely affected due to climate change (Titumil and Basak 2010).

The varied climatic conditions in the farming systems of Sri Lanka have given rise to a wide range of crop species and land races that are suited for different conditions of soils, rainfall, and altitude as well as to diseases and insect pests. Genetic diversity is particularly high among rice, other cereals, cucurbits, and vegetables such as tomato and eggplant, indicating the potential for crop improvement in the face of natural disasters such as climate change, as an adaptation measure. The genetic diversity of crop plants is the foundation for the sustainable development of new varieties for present and future challenges. Resource-poor farmers have been using genetic diversity intelligently over centuries to develop varieties adapted to their own environmental stress conditions. Systematic crop comparison programs under different agroecological regions of Sri Lanka through farmer participatory programs, strengthening the crop germplasm collection programs conducted by the Department of Agriculture with special focus on climate change, and creating access to and drawing in new genetic materials through intergovernmental programs to enhance food production would strengthen the strategic approaches for adaptation in Sri Lanka, thus minimizing the climate risk on food security.

In spite of the technological advances made on improved crop management, irrigation, plant protection, and fertilization, weather and climate are still key factors in agricultural value chain in Sri Lanka. Farming systems and agronomic practices in most agricultural regions of Sri Lanka have evolved in a close harmony with the prevailing climatic conditions of respective climatic regions of the island. However, it has been evident during recent decades that heritage of farming experiences and accumulated weather lore of centuries have become ineffective in agricultural planning process at all levels. The climate of the island has undergone a change to such an extent that correct amount of rainfall does not come at the correct time of the growing season.

Variability of both summer and winter monsoon rains and rains of convectional origin has increased significantly during recent decades in the world. As a result, both extremes, i.e., water scarcity and excess water, have become a recurrent problem in crop production and its entire value chain in Sri Lanka. More flexible farming approaches with water-efficient farming methods and crops to improve water productivity, construction of new reservoirs and trans-basin diversions to meet the demand, and management of water resource systems that respond to existing soil moisture and water storage levels are thus essential adaptation strategies to be used coupled with an improved climate forecast system.

Increasing ambient temperature is also inflicting several direct and indirect negative impacts on the crop growth. Urgent coping-up strategies such as identification of new areas for crop production, introduction of new climate-resilient crop varieties, organic agriculture, cropping systems including agroforestry, rainwater harvesting systems, and micro-irrigation techniques would assist in overcoming the negative impacts of higher environmental temperatures.

The intensively managed animal production sector is hardly vulnerable to the climate compared to impacts on the food crops sector. Nevertheless, the situation is obviously different for the extensively managed animal production sector where it is purely dependent on the rainfed pastoral systems and subjected to direct influence of climatic conditions. The animal production sector of Sri Lanka is signified mostly by smallholders spread across varying climatic regimes. The localized impacts of climate change are more visible in the areas where smallholder and subsistence farming are practiced as they are highly vulnerable to the localized trends of climate change. However, the high genetic variability that exists, especially among indigenous animal categories, and their adaptability to the diverse and localized climatic regimes in the country render a positive influence in building up resilience in smallholder sector by balancing the impacts of climate variability within the system of farming. Despite the importance of smallholder systems to the animal production sector of Sri Lanka, an understanding on the interaction of climate change and animals in the country is not effective enough to face the future development challenges of the sector.

Irrespective of the sectoral characteristics, the impact of climate change on any sector depends on how and what intensity the rainfall regime in a given area is variable along with the increasing environmental temperature of the same area. In addition, if the area lies in a coastal environment, the sea-level rise and the risk of increased storm surge would bring in more additive negative effects.

Impacts of Changes in Rainfall and Soil Regimes on Food Security

Increased occurrence of extreme rainfall events due to climate change, droughts, and floods has become a common feature of the climate of Sri Lanka during recent decades. It is clear until the mid-1980s that any within- or between-season variation in rainfall could be statistically accommodated within a 95 % confidence interval. However, weather aberrations that have taken place after the late 1980s could be considered as unprecedented because they fall outside even the 90 % confidence limits. Under such situations, crop losses due to decreased soil moisture and excess water, both in terms of quantitative and qualitative, are inevitable.

In Sri Lanka, more than the temperature regime, the amount and distribution of seasonal rainfall have a profound impact on the productivity and food security in different agroecological environments. Out of the 46 agroecological regions of the country, 31 of them spreading across both Dry and Intermediate Zones are more delicately poised than those of the Wet Zone in relation to rainfall seasonality and variability. Aberrations or change in rainfall pattern will therefore have a major impact on food security in the Dry and Intermediate Zones. These two climatic zones have four major great soil groups of agricultural significance, namely, reddish brown earths (RBE), non-calcic brown soils (NCB), red-yellow latosols (RYL), and regosols, that will be affected at varying degrees under variable and changing climate, thus affecting food security of the country, as described below.

Reddish-Brown Earth Region

Reddish-brown earth (RBE) is the most widespread great soil group of Sri Lanka, and it occupies mainly in DL_{1a}, DL_{1b}, DL_{1c}, DL_{1d}, DL_{1e}, DL_{1f}, DL_5, and IL_2 agroecological regions covering an aerial extent of 1.61 million hectares. The soil moisture relationships of this soil are characterized by a low water holding capacity with a rapid release of soil moisture at tensions lower than one atmosphere. It is also characterized by having a gravel layer in the sub-horizon. The depth to this gravel layer is quite variable, depending on the agroecological region. Due to the aforesaid soil moisture characteristics of this soil group, negative anomalies of seasonal rainfall that may arise frequently under a changing climate will manifest as drought injuries in upland crops at varying degrees. It is equally true that the positive anomalies of seasonal rains could lead to excess soil moisture conditions with drainage problems in upland crops due to impervious gravel layer in the subsoil of this soil group.

About 80 % of the country's coarse grains (i.e., maize and millet) and grain legumes (green gram, cowpea, black gram, and soybean) are grown on this soil group during the *Maha* season in the above-stated agroecological regions. Thus, it is likely that climate change would exacerbate the crop losses and severe instability in a year-to-year production in those farming systems due to drought and excess soil moisture conditions.

The other most dominant farming system associated with this soil group is rice cultivation in irrigable lowland during the *Maha* season and perhaps during the *Yala* season depending upon the availability of water in the tank system (irrigation reservoirs). These tanks have been constructed as a cascade system by blocking the natural drainage ways in a watershed by means of earthen dams to collect the rain and runoff at appropriate places to form a series of small tanks along the drainage way. More importantly, these tanks, known as the "minor tanks" (reservoirs with an irrigable area of less than 80 ha), provide the livelihood of a large section of the rural population in the RBE region. An estimated number of 8,500 working minor tanks are reported to provide water for 43 % of the total irrigated area in the country. These estimates suggest the great importance of minor tanks in Sri Lanka, especially for the RBE region. Generally, the catchment of these tanks is relatively small, owing to the undulating landscape of the region.

Shifting cultivation or chena cultivation is the common land use practice in these catchments for decades by the villagers, and as a result catchment yield has been declining gradually over the years. Apart from reduced inflow to the reservoirs, chena cultivation has also led to soil erosion and subsequent sedimentation of tanks, leading to reduced storage and increased surface/depth ratio.

Rainfall regime in this region has become highly erratic during the recent times due to climate change, resulting in below-average storage conditions even during

Maha seasons. Meanwhile, increasing ambient temperature regime, coupled with high surface/depth ratio of tanks in this region, has resulted in rapid drying out of these tanks to make the situation become worse. All these have led the farmers who find their livelihood from these tanks to look for other livelihood alternatives or migrate to urban areas for nonagricultural livelihood options.

Non-calcic Brown Region

The non-calcic brown (NCB) soil group is mainly confined to DL_{2a} and DL_{2b} agroecological regions in Ampara and Batticaloa districts along with the IL_3 region in the northern part of Kurunegala district, covering a total area of about 165,000 ha. This is a coarse-textured soil with very poor chemical properties. Due to the unimodal nature of rainfall pattern in the DL_{2a} and DL_{2b} agroecological regions, only a single crop is possible in those regions during the *Maha* seasons.

During the recent times, the variability of NEM has been increased dramatically due to climate change, and as a result a significant instability in season-to-season rainfed agriculture production is inevitable in this region. Nevertheless, wetland rice cultivation in valley bottoms, where NCB occurs in a complex association with relatively fertile old alluvium soils, may manage to give good yields even under a changing climate unless extreme positive rainfall anomalies cause flood damages in these regions. The IL_3 agroecological region in Kurunegala district is frequently subjected to moisture stress due to its own rainfall pattern and coarse texture of the underlying soil. Thus, negative anomalies of rainfall may aggravate the drought injuries in this region even with the dominant tree crop of coconut.

Red-Yellow Latosol Region

The great soil group red-yellow latosol (RYL) mainly occurs in the DL_3 agroecological region in the Northern Province with an aerial extent of 320,000 ha. It generally overlies a very porous limestone substrate, which provides a stable groundwater source throughout the year. Cultivation of high-value crops such as chili, onion, and vegetables under lift irrigation is the common cropping system in this region. Even though it was used to be a sustainable land use system with traditional lifting devices (*Thula Kinnaru*), the use of motor-powered lifting pumps has exponentially increased the rate of groundwater extraction, which could increase the vulnerability of the farming system to climate change.

Regosol Region

The regosol soils are located mainly on the elevated beach plains with a flat topography in the Batticaloa and Puttalam districts. Despite the dry environment that prevails in these regions, the soil supports very productive coconut plantations and cashew cultivations by underlying freshwater supplies found at a shallow depth. In some places (Kalpitiya peninsula), these soils have been widely used for intensive cultivation of high-value crops such as chili, onion, and vegetables under lift irrigation from shallow wells. However, extraction of water extensively from the shallow water supply would make the entire farming system in these regions highly vulnerable to climate change, even posing threats to drinking water supplies of the community.

Generally, rice cultivation in the Dry and Intermediate Zones possesses a considerable resilience to climate change compared to other cropping systems in those regions due to the availability of irrigation water. The animal component of the widespread mixed (crop-animal) systems across all the above regions will have an indirect influence of the rainfall pattern and soil regime due to the changes in feed availability. A recent study has shown that even the Wet Zone of Sri Lanka is undergoing significant changes in its rainfall rhythm (Premalal and Punyawardena 2013). Some years have become "years of extremes" where within a shorter time period (i.e., 1 month), a flood-stricken area of the Wet Zone could turn into a drought-affected area.

Impact of Floods and Drought on Food Security

In the food crop sector, the occurrence of floods has affected paddy production in Sri Lanka significantly compared to other crops, with heavy damages being recorded during *Maha* season 2008/2009, resulting from a peak of flood incidences in December and March. Kilinochchi and Ampara districts in the Dry Zone of Sri Lanka have reported the highest losses of paddy due to flooding during the 6-year period from 2005 to 2010 (Fig. 8).

Poultry industry was highly affected by flood incidences during the period 2005–2008 when compared to the rest of the animal production sector. Losses in the animal production sector were high during the *Maha* season, as in the case of crops, and the month of December has recorded the peak of animal losses due to floods. Kilinochchi, Jaffna, and Ampara districts have shown higher levels of animal losses due to the occurrence of floods during the period 2005–2010 (Fig. 9).

The continuous occurrence of drought over the years has resulted in a consistent pattern of crop damage, with a severe impact recorded in 2009. Crop losses were higher at the onset of the *Yala* season and at the end of the *Maha* season. The highest crop losses were observed in Kurunegala (Intermediate Zone) and Matale (Wet Zone) districts during the period 2005–2010 (Fig. 10).

Drought has also affected the poultry and cattle industries over the period 2005–2010. The cattle industry was significantly affected by drought especially during 2006 and 2007, while the poultry industry was badly hit in 2009. The highest animal loss was observed in Kilinochchi and Batticaloa districts in the Dry Zone during the period 2005–2010 (Fig. 11).

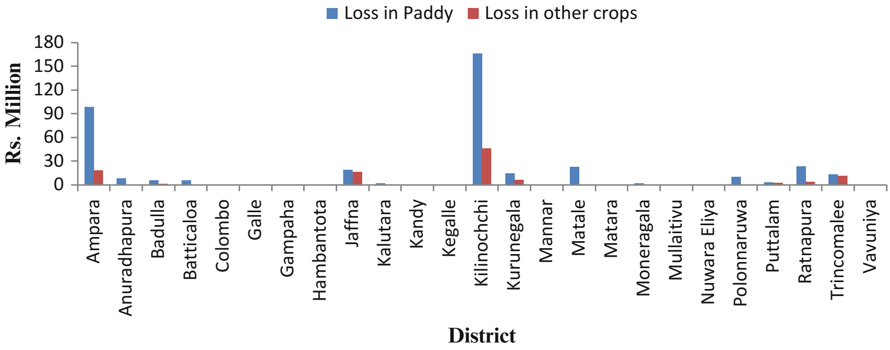


Fig. 8 Spatial distributions of crop losses due to the occurrence of floods in Sri Lanka during the period 2005–2010 (Source: www.desinventar.lk)

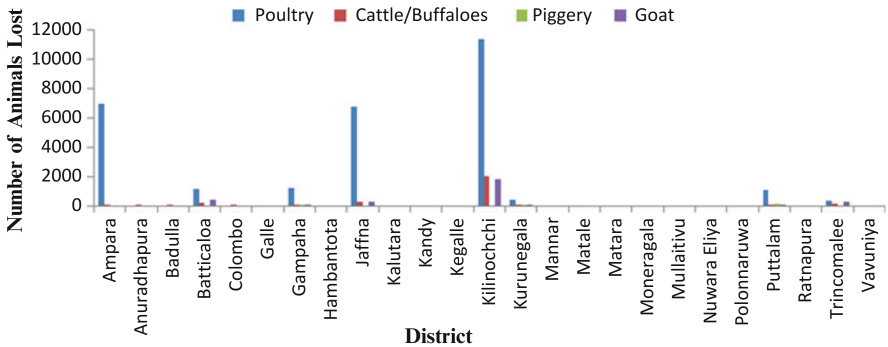


Fig. 9 Spatial distributions of animal losses due to the occurrence of floods in Sri Lanka during the period 2005–2010 (Source: www.desinventar.lk)

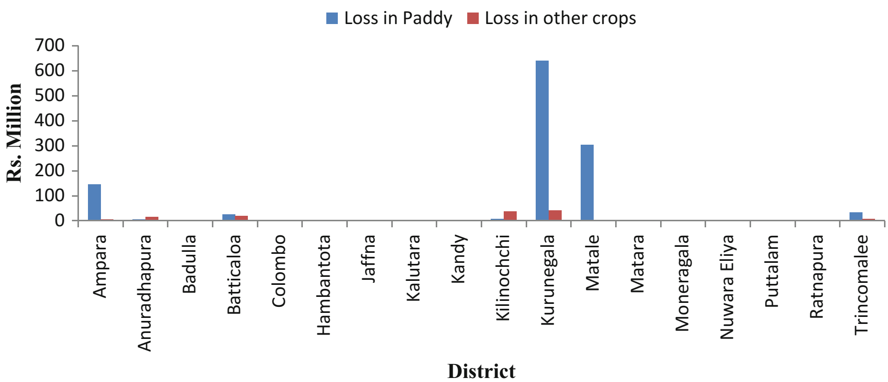


Fig. 10 Spatial distributions of crop losses due to the occurrence of drought in Sri Lanka during the period 2005–2010 (Source: www.desinventar.lk)

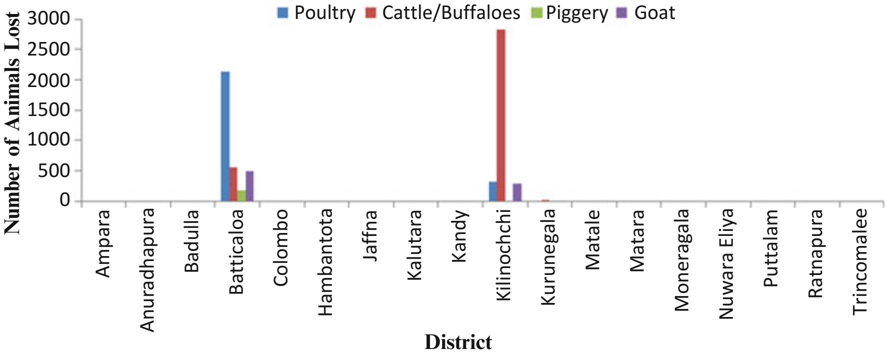


Fig. 11 Spatial distributions of animal losses due to the occurrence of drought in Sri Lanka during the period 2005–2010 (Source: www.desinventar.lk)

Impacts of Increased Temperature Regime on Food Security

Being a tropical island with a uniformly high-temperature regime, most of the cultivated crops in Sri Lanka operate near the maximum of the optimum temperature range of respective crops. This phenomenon is true for animal production, too. Thus, crop injuries and animal production losses due to high temperatures are inevitable in Sri Lankan agriculture with increasing temperatures. This is of particular importance for the country's major staple food, rice. It is a well-established fact that high-temperature injuries in rice are inevitable if the plant is exposed to an ambient temperature that exceeds 33 °C just for 60–90 min at the anthesis stage (flowering; Punyawardena 2011). It was used to be a rare event to experience such high values of daytime temperature in major rice-growing regions of the country; however, recent agro-meteorological observations have confirmed that the frequency of such temperature events has increased significantly in both Dry and Intermediate Zones, especially during *Yala* seasons, resulting in high rates of unfilled grains due to increased spikelet sterility (known as *Ehela Pussa*). Higher temperature regimes will also increase the evapotranspiration losses, leading to frequent soil moisture stress conditions in upland crops. Recent investigations have clearly shown that the nighttime minimum temperature in many locations of the country has been increasing during recent decades, resulting in diurnal temperature range to become increasingly narrower.

Even though root and tuber crops are more resilient to temporal variations of rainfall, a decreasing trend of diurnal temperature range is likely to cause negative impacts on the root and tuber crop production in the country. This will be highly reflected in potato production in the central hills as the existing environmental temperature regime is suboptimal for the crop even in the up-country region where the crop is mainly concentrated. The quality of the harvestable parts of crops is also to be affected negatively due to several reasons, which may arise due to climate change.

Increased temperature, especially the nighttime minimum temperature, tends to decrease the sugar translocations to harvestable fruits and thus reduce the quality by increasing sour taste in fruit crops. Meanwhile, the fiber content of the harvestable parts of crops is also likely to increase under increased temperature regimes, thereby reducing the palatability of them.

The heat stress conditions in animals under increased ambient temperature reduce the fertility and productivity of all categories of livestock and poultry, especially in high-yielding exotic breeds. This has a direct influence on production losses in the case of dairy and egg production. As the heat load accumulation inside the animal body has a profound adverse effect on the rate of growth, the meat production also gets affected significantly irrespective to the system of operation, intensive or extensive.

The yield of almost all crops grown and animals reared in the country would also be negatively affected due to increased insect pest damages and infestation by all kind of pathogens such as bacteria, virus, and fungi especially under humid conditions. Even though higher yield losses due to increased weed infestation are likely to occur with increasing temperature, recent studies have shown that there is no such trend under local conditions. However, it is too early to generalize that such threats would not occur in the future.

Apart from the direct impact of increased variability of rainfall and rise of ambient temperature, indirect effects of increased rainfall intensities are of special significance in terms of land degradation, which has a significant bearing on the crop production in Sri Lanka. Increased temperature is likely to enhance the local-scale convection and thereby to form more cumulonimbus clouds, giving rise to high-intensity rains (>25 mm/h). Such rains invariably will wash away the fertile top soil of arable lands and will lead to subsequent siltation and eutrophication of downstream reservoirs and any other surface water bodies. Moreover, increased temperature and frequent and negative rainfall anomalies are also likely to cause high evaporative demand of the atmosphere. This can cause salinization of agricultural lands in the semiarid parts of the country.

Impacts of Sea-Level Rise on Food Security

Being an island, Sri Lanka is highly vulnerable to sea-level rise with varying degrees of sectoral impacts. It is highly confident that seawater intrusion to agricultural lands will be an inevitable event under a changing climate, which will lead to further reduction of land available for agriculture.

Increased sea-level rise will also exacerbate the coastal erosion, giving rise to some additional pressure on land available for agriculture, directly and indirectly. Also, it may reduce the quality of both drinking and irrigation water in coastal regions by disturbing the interface between freshwater and brackish water. It is highly likely that sea-level rise will disturb the Ghyben-Herzberg lens of freshwater found underneath of regosol in coastal regions. These freshwater lenses provide the irrigation water for intensive agriculture in those areas.

Adapting to Climate Change Aiming at Food Security

Being cognizant of the importance of adapting to climate change, the government of Sri Lanka has taken several initiatives at the policy level by developing the National Climate Change Policy (NCCP) of 2012 (Ministry of Environment 2012) and the National Climate Change Adaptation Strategy (NCCAS) 2010–2016 (Ministry of Environment and Natural Resources 2010). While the three main policies that deal with the agriculture sector related to food security, namely, the National Agriculture Policy of 2007 (Ministry of Agriculture and Agrarian Development 2007), National Livestock Development Policy of 2007 (Ministry of Livestock and Rural Community Development 2007), and the National Fisheries and Aquatic Resources Policy of 2006 (Ministry of Fisheries and Aquatic Resources 2006), are in operation, the NCCP and NCCAS are expected to mainstream climate change adaptation into the national planning and development process.

Rice

Rice being the major staple of Sri Lankans, more efforts have been made by the scientific community to provide suitable materials resilient to changing and variable climatic scenarios. A recent study has indicated that rice farmers in the Kurunegala district of Sri Lanka (Intermediate Zone) have lost 44 % of the agriculture income every season due to drought (Chandrasiri 2013). Chandrasiri (2013) also reported that the awareness of climate change among the farmers is high, but the adaptation is poor due to the lack of knowledge on adaptation methods, unavailability of prior information on climate change, absence of suitable cultivars, and lack of funding. A recent study (Herath and Kawasaki 2012) also reported that the variability of rice yield under the future climate conditions in the Kurunegala district of Sri Lanka shows small increasing trends, averagely 1.7 % and 2.4 % under the A2 and B2 scenarios, respectively. More yield-improving techniques are required to achieve the future rice requirement of the country under the impacts of climate change.

Several successful attempts have been made in the rice production sector in the technological front to meet the challenges of climate change. The development of rice varieties, which are of short duration and suitable for short growing seasons (Harris and Shatheeswaran 2005) and high CO_2 concentration (De Costa et al. 2007), is in the forefront of technological innovations. The recent release of ultrashort-duration rice varieties by the Sri Lanka Department of Agriculture such as Bg250 maturing in 75–80 days is a positive response by the government of Sri Lanka to cope up with climatic changes. Gunawardana et al. (2013) reported on the potential for adoption of aerobic growing conditions for rice varieties minimizing the water use under changing climatic conditions while assessing the competition for weeds.

Studies carried out in Sri Lanka to identify the role of traditional paddy varieties and organic practices in adapting to climate change especially in the coastal belt have indicated that farmers have perceived climate change in rainfall patterns, intensity and timings, changes in the cloud formations, and other indicators such as the behavior of animals. As the sustainability of food production through traditional farming patterns is being challenged, farmers have been following water-conserving agronomic practices such as *Kekulama* or *Manawari* system and *Nava Kekulama* (dry-sowing systems; Upawansa 2013) and the System of Rice Intensification (SRI) (Somaratne 2010) and are also making informed choices in species selection by combining local knowledge on species and varieties under the guidance of several NGOs (Berger et al. 2009). Jayawardena et al. (2010) reported that paddy cultivation in the Dry and Intermediate Zones in Sri Lanka under zero-tillage condition has enabled a reduction in cost of production and enhanced water conservation without significantly affecting the yield. Breeding of salt-tolerant rice varieties is also a primary adaptation measure to maintain national rice production levels and ensure food security in the face of expanding salinity due to sea-level rise. In this regard, the salt-tolerant rice variety At354 (3½ month age class) has been developed by the Sri Lanka Department of Agriculture to meet food production challenges under saline conditions. Salinity in paddy fields could also be overcome by a combination of agronomic measures including improved field drainage, application of organic manure, rice straw and burnt paddy husk, and transplanting rice instead of direct seeding.

With more frequent extreme rainfall events, the area under major irrigation reservoir schemes (reservoirs with an irrigable area of more than 200 ha) in the Wet and Intermediate Zones that practice rice + rice annual cropping pattern would not be able to claim the usual share from the trans-basin diversion structures. This has forced the farming community to reduce the extent under cultivation or explore other adaptation options such as “shared cultivation” (*Bethma* system) but at the expense of the productivity of the system. Moreover, increased occurrence of extreme positive rainfall anomalies is likely to cause severe damages to existing irrigation infrastructure of major irrigation schemes, thus limiting the water availability for crop production systems under these reservoirs.

Traditional agriculture practices coupled with endogenous paddy varieties have proven to be more successful in facing climate change events such as droughts and floods (Sharma and Rai 2010). There are many traditional paddy varieties in existence today in Sri Lanka, which have strong characteristics that help them survive climate change impacts such as droughts, heavy rains, and floods compared to newer varieties used in chemical-intensive paddy cultivation (Rathnabharathi 2009). This vigor is based on certain characteristics unique to traditional paddy varieties. The traditional varieties are capable of surviving in the nursery until the field conditions are favorable for planting. Traditional varieties are tall with a strong stem compared to the new improved varieties, thus helping them to withstand heavy rains, winds, and droughts. The husk of the paddy seed of traditional varieties can withstand waterlogged as well as drought conditions (Rathnabharathi 2009). Traditional rice varieties such as *Hata da vee* that survives long dry spells are being cultivated in selected areas in the Dry and Intermediate Zones of the country. Farmers are being assisted by several NGOs to identify traditional paddy varieties such as *Pokkali*, *Kaluheenati*, and *Madathawalu*, which can be grown in sandy and saline soils with appropriate management practices. To cope with shifting seasons due to unpredictable fluctuations in rain and temperature, long- and short-age traditional varieties such as *Hata da vee* (maturing in 70 days) and the *Maha ma vee* (maturing in 6 months) are cultivated by farming communities in different localities of Sri Lanka. Paddy farmers under the minor tank systems in the Dry Zone of Sri Lanka are aligning farming activities with the recognized seasonal pattern of rainfall and managing rainwater harvested in the commonly owned village tanks (Senaratne and Wickramasinghe 2010). Amarasingha et al. (2014) reported that changing planting date of rice according to the onset of rainfall can reduce the irrigation water requirement and risk of rice cultivation. Early onset of rainfall coupled with early planting has resulted in higher yield and water productivity across different irrigation management options, while a higher variability has been observed in both water productivity and yield at a late onset and planting with subsistence irrigation. Dharmarathna et al. (2014) also reported that advancing the rice planting date by 1 month would be a non-cost climate change adaptation strategy for rice production in the Kurunegala district of Sri Lanka.

Coconut

Analysis of coconut production data from 1971 to 2001 has shown that the foregone income to the economy due to crop shortages from unfavorable climate has varied around US$ 32–73 million (Fernando et al. 2007), and the additional income to the economy from favorable climate years producing a crop glut was US$ 42–87 million. This implies the potential for significant economic benefits from investments in adaptation that would reduce the variability in coconut production, caused by variation in climate. Some varieties such as Tall x Tall and Tall x San Ramon have been recommended for drought-prone areas in Sri Lanka to meet the challenges of climate change. Furthermore, the variety Dwarf Brown appears promising for plant breeders as an ideal parent material due to some characteristics such as nonseasonality, high-yielding capacity (higher number of nuts per bunch and higher number of inflorescences per palm per year), and relatively higher tolerance to water stress conditions compared to those of other dwarf varieties (Ministry of Environment 2010).

Other Food Crops

Several strategies have been adopted in the other food crops sector (excluding rice), covering many food crops at the national and household level to cope up with the changes in climate, such as (a) soil moisture conservation with mulching, soil erosion control under intensive rainy conditions to minimize surface runoff and improve the water-retention capacity of soil; (b) growing low water-demanding crops such as mung bean (green gram), finger millet, and sesame and short-age crops for mid-season cultivation with appropriate agronomic management practices; and (c) adjusting the cropping calendar according to changes in the rainfall pattern (Howden et al. 2007).

Animal Production

Livestock and poultry form an important subsector in the social and economic context of the country, and hence strategies for adaptation and risk aversion to face the challenges brought by the changing and variable climatic conditions are crucial. Strategies for climate change adaptation have not been specifically highlighted in the National Livestock Development Plan – 2010 (Ministry of Livestock and Rural Community Development 2010), which is implemented at present. The animal production sector implements a strategic approach in animal breeding activities since 1994 according to the climatic regions by using different animal breeds and their crossbreds.

A greater emphasis has been given for the dairy subsector in the implementation of breeding strategies as the country's main strategy in terms of food security in relation to animal production is to bring self-sufficiency in milk and milk products. The interim target has been set to achieve 50 % self-sufficiency by the year 2015. However, there are no pasture development strategies or recommendation in place according to the climatic conditions due to various limitations that exist in the field level. Given the fact that Sri Lanka possesses a diverse climate as well as production environments, the benefit of development of climate-resilient systems for feed improvement is still pending.

The subsectors other than dairy have breeding strategies specified for each sector, considering the adaptability of different genotypes. In addition, sustainable utilization of indigenous animals has been specifically identified in the animal breeding guidelines (Ministry of Livestock and Rural Community Development 2010). Many efforts have been taken in the past in developing locally adopted breeds suitable for different climatic regimes in the country. Kottukachchiya goat breed (Silva et al. 2010) developed as a dual-purpose breed suitable for the Dry Zone in Sri Lanka and CPRS poultry breed (Gamage et al. 2013) developed for local climatic conditions and feeding regimes are few examples of such attempts.

Homegardens

"Homegarden" (HG) is a complex but sustainable land use system that combines multiple farming components in the homestead and provides environmental services, household needs, employment, and income-generation opportunities to the households (Weerahewa et al. 2012). A study conducted to assess the vulnerability of HGs to climate change and its impact on household food security in Sri Lanka (Marambe et al. 2013) has identified four categories of climate change adaptation strategies adopted by homegardeners, namely, (1) changing planting date, (2) changing agronomic practices, (3) changing technology such as the use of new varieties and irrigation equipment, and (4) the use of soil and water conservation measures. Family size and perceptions on climate change have positively affected the likelihood of adoption of new technologies in Sri Lanka. Male-headed households also tend to adapt more than that of the female-headed households. The factors that negatively affect adaptation in Sri Lankan HGs included ownership of animals, HG size, age of the head of the household, and plant diversity of the HG (Marambe et al. 2012). Commercial orientation, perceptions on climate changes, years of experience of the homegardeners, and location of farming have significantly influenced the probability of adoption of adaptation strategies (Daulagala et al. 2012).

Conclusions and Way Forward

The sustainable development challenge remains urgent and acute, where poverty and food insecurity impact the lives of a sizable population in developing countries including Sri Lanka. Climate change renders achieving the national-level food security more challenging, thus making sustainable development a daunting task. The United Nation's Rio+20 summit in 2012 has thus committed governments to create six Sustainable Development Goals (SDGs) to be integrated to the follow-up of Millennium Development Goals (MDGs) after the 2015 deadline. A new approach for long-term sustenance in food security is a necessity by effectively drawing in ecological principles to improve the productivity and efficiency of agriculture and food systems while reducing negative environmental impacts. Substantial gains in productivity in agriculture and food systems can be realized through investment, innovation, policy, and other improvements.

Agriculture and food systems face many challenges, making it more difficult to achieve the primary objective of meeting the world food demand. An intimidating set of unprecedented challenges and risks including the increasing competition for land, water, and other natural resources by nonagricultural sectors affect the food security of the current and future inhabitants of the world. Food security is multidimensional, and the population growth and changes in consumption patterns associated with rising incomes drive greater demand for food and other agricultural products. Advancements in the productivity frontier, transformations in production systems, and enhanced food and environmental safety are three goals to achieve by countries, and Sri Lanka is not an exception.

Climate change has continued to affect agricultural productivity (crops and animals) through shifts in rainfall patterns, changing temperature regimes, and increased climate variability as well as climatic extremes. Farmers in Sri Lanka have observed these changes, but their historic weather knowledge and experience are progressively becoming less useful in the agricultural planning process due to the rapid changes in the climate. The existing short-term (3–10 day) weather forecasts have provided limited assistance for planning in the agricultural sector, and hence, access to reliable intra-seasonal to seasonal climate forecasts (1 month to multi-month time frames) could provide farmers with a complementary set of response options, which can further help reduce production risks and ensure food security. Such mid-range forecasts could assist farmers and the policy makers to develop improved climate risk management strategies such as which crop to be planted and when, fertilizer application rates, and timing of irrigation activity and harvest. While seasonal climate forecasts in the tropical systems have been a challenge for modelers globally, valuing existing or even marginally improved forecasts could effectively be included in decision making in agriculture.

Effective intra-seasonal to seasonal management responses to short-term climate variability are key means to progressively adapt to climate change (McKeon et al. 1993).

Climate-resilient food production approaches would be the path to sustain food security for sustainable development in Sri Lanka. A research agenda closely tied to sharing of information across research, i.e., discovery, development, and deployment, is an imperative. Advancements in productivity frontier, transformations in production systems, and enhanced food and environmental safety are three priority research themes in this regard in the attempt to adapt to climate change scenarios while ensuring food security. The purpose-driven research in sustaining food security should address: (1) seasonal climate forecasting with appropriate statistical models and numerical weather predictions, crop/animal growth modeling with appropriately parameterized models, and assessment of adaptation and resilience levels of different crops and animals; (2) judicious use of wild relatives and natives for breeding/propagation for quality products and biotic and abiotic stresses, reengineering crop photosynthesis, and reverse phenology; (3) introduction and promotion of the use of precision agriculture, smart fertilizers, agroforestry, climate-smart agriculture, watershed management to minimize soil erosion and environmental contamination, and water-saving irrigation techniques; and (4) reduction in waste related to agriculture and food aiming at food safety, improved food and nutrient use efficiency, recycling and reuse, value addition, and value chain management. Realizing these goals will require an exceptional level of collaboration among stakeholders in the agriculture value chain including the government, private sector, civil society groups, academia/scientists, farmers, and consumers. Science and technological progression will make it possible for sustainable agriculture to become the new global standard, but the main factors resisting this change are political will, lack of policy coherence at many levels, financing, governance, and human behavior.

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Climate Variability and Climate Change Impacts on Smallholder Farmers in the Akuapem North District, Ghana

Kwadwo Owusu, Peter Bilson Obour, and Selina Asare-Baffour

Contents

Abstract

Climate change is unequivocal and these changes have increased over the past few years. The recent vulnerability and prospect of climate variability and change impact, thus, warrants measures now to reduce the adverse impacts. This is especially important in relation to smallholder farmers whose activities provide large proportion of the food consumed in the developing world, especially in sub-Saharan Africa. A qualitative approach was used to collect data on the perceptions of smallholder farmers from three communities in the Akuapem North District in Ghana. The perceptions of the farmers about rainfall changes were compared with the empirical daily rainfall total data from the Ghana

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Meteorological Agency to corroborate changes in rainfall. By comparing the perceived changes in the rainfall of the district with the empirical data, it was identified that shifts in the rainfall regime was the main cause of crop failures in the study area but not decline in the annual rainfall total. Farmers being aware of changes in the rainfall have employed new stresses to improve their productivity. However, it was observed that non-climatic stresses such as low capital and absence of institutional support in the district have increased smallholder farmers' vulnerability.

Keywords

Adaptation • Akuapem North • Climate change • Climate variability • Ghana • Smallholder farmers • Subsistence agriculture • Vulnerability

Introduction

Climate change is unequivocal according to the Intergovernmental Panel on Climate Change (IPCC), as there is now ample evidence that the earth's climate system is warming at an unprecedented rate leading to ice melting and sea-level rise (IPCC 2007). No wonder the impact of climate variability and change has taken a center stage in many scientific research worldwide (Hulme et al. 1999; Tauli-Corpuz and Lynge 2008). In the coming decades, global climate change will have an impact on all sectors of the global economy. But most impacts will fall on the agricultural sector, creating food insecurity and heightened water stress, most especially in the developing world (Ringler 2008; Nelson et al. 2009). Poor farmers who are (referred to as subsistence or smallholder farmers) and predominantly in the low-latitude developing countries living in remote and fragile environments are expected to become the most vulnerable (Altieri and Koohafkan 2008; IFAD 2008). According to IFAD (2010), by 2050 food production needs to increase by 70 % but the total arable area in developing countries may increase no more than 12 % mostly in sub-Saharan Africa and Latin America. This implies that the burden of increasing food production rests on the shoulders of these farmers whose occupation would be most affected and who are also poor and technologically deficient to master effective adaptation. Morton (2007) describes smallholder farmers as rural producers, predominantly in the developing countries, who farm using mainly family labor and for whom the farm provides a principal source of income. Their activities depend directly on climatic factors while climate also indirectly affects the terrain and the environment on which they depend.

Smallholder farmers are the backbone of the rural economy but bear the brunt of climate change impacts (IFAD 2009). Worldwide, there are 500 million smallholder farms supporting some 2 billion people. Smallholders provide up to 80 % of food consumed in Asia and sub-Saharan Africa. Although it is held that some regions in the world will enjoy increase in agricultural production as a result of climate change (a slight increase in temperature could increase crop production in higher-latitude regions), the net impact of climate change on sub-Saharan Africa would be negative (Boko et al. 2007; Vermeulen 2011).

Khamis (2006) stated that smallholders in Malawi have been exposed to tremendous drought and flood affecting food security and their livelihood. In Ghana, food security and rural incomes are under threat from unpredictable changes in rainfall and shifts in the rainfall regime (Owusu and Waylen 2009, 2013). The smallholder farmer in Ghana is facing the negative impacts also as a result of many non-climatic stresses that make him or her vulnerable. In developing countries in general, vulnerability of smallholder farmers to climate change impacts has been exacerbated by non-climatic stresses like population increase, low capitalization, rural–urban migration, health problems like HIV/AIDS and malnutrition, government policies, and market shocks (Morton 2007; Osbahr et al. 2008; Francis 2002). In Ghana in particular, lack of credit, lack of storage facilities, low levels of technology, lack of access to market, and land tenure complications which occasionally result in conflicts have heightened the smallholder farmer's vulnerability to climate variability and change (Kunateh 2011). Such stresses have been exacerbated by the fact that smallholder activities in the country are mainly rain-fed. For example, the total arable land under irrigation in Ghana was reported to be less than 3 % (GIDA 2010; MOFA 2011).

Climate change poses serious problems for these farmers to deal with since their main source of livelihood is being threatened through "crop failures and livestock death leading to economic losses, high food prices thereby undermining food security" (IFAD 2009). It is thus very important to assess how climate variability and change affect the living conditions of smallholder farmers since they are responsible for cultivating a greater chunk of arable lands in Ghana. Over the years, smallholders have learned to adjust to climate variability and change to increase agricultural sustainability (AAFRD 2005). However, the current speed and intensity of climate change and associated extremes are posing problems for smallholders and their capacity to adapt. This is more so as the prospect of adverse climate variability and change is not going to diminish in the very near future (Downing et al. 1997). This chapter investigates the impacts of climate change and its effects on the incomes and food security of the smallholder farmers in the Akuapem North District of the Eastern Region of Ghana. The adaptation strategies used by the smallholder farmers are also examined. The objectives are to assess smallholder farmers' perception and knowledge on climate change and the related risks, to account for the factors other than climate which make smallholders vulnerable to climate variability and change, and, finally, to assess the various mechanisms used to reduce the effect of climate variability and change on their system of farming.

Conceptual Framework for Smallholder Farmers' Vulnerability to Climate Change

In this study, the conceptual framework proposed by Morton (2007) was adapted to understand the various ways in which climate change impacts on the livelihoods of subsistence farmers and how such impacts heighten their vulnerability.

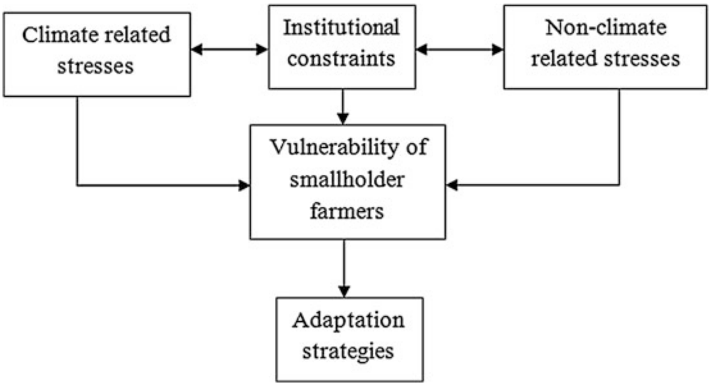

Fig. 1 Conceptual framework for climate change impacts on smallholder farmers (Source: Adapted from Morton 2007)

The framework distinguished between climatic and non-climatic stresses which integrate together to impact on smallholder farmers. Climate-related stresses such as droughts and floods affect farmers in diverse ways such as constraints on soil quality and inducing crops and animal diseases (Scoones et al. 1996; Lal 2000). The non-climatic stresses on the other hand include land fragmentation due to population growth, market failures, and prevalence of diseases affecting the health of farmers (Morton 2007).

However, as indicated in Fig. 1, unlike Morton's originally proposed framework, another impact propeller "institutional constraints" (such as public, private, and civil society support) was introduced. The reason for distinguishing between institutional constraints from non-climatic stresses is that, if well managed, institutional supports are able to cushion the impacts of both climatic and non-climatic stresses and vice versa (Agrawal and Perrin 2008).

It must be pointed that the effects of the three (3) distinguishing stresses on smallholder farmers' vulnerability depend on their sensitivity and resilience capacities (IPCC 2007). But in order to reduce such vulnerabilities, this study will examine the different livelihood adaptive and coping strategies that smallholder farmers adopt in order to reduce the risks and shocks of the stresses. The study also outlines the roles of institutions in climate change adaptation in the Akuapem North District of Ghana.

Study Area

The Akuapem North District is one of the administrative districts in the Eastern Region of Ghana and is located in the southeastern part of the region. Akropong, the district capital, is roughly 58 km from Accra. The district lies between latitude 5° 5′ North and 6° 8′ North and longitude 0° 4′ West and 0° 19′ West. It shares boundaries to the northeast with Yilo Krobo, north with New Juaben Municipal, southwest with Akuapem South Municipal, and in the west with Suhum-Kraboa-Coaltar District. The Akuapem North District covers a land area of about 450 km^2, representing 2.3 % of the total land area of the Eastern Region (Ghana Districts.com 2006) (see map of district in Fig. 2).

The vegetation of the district is made up of a mixture of forest and shrub. Geologically, the district is dominated by rocks of the Precambrian era, the Togo and Birimian series. Its terrain is mountainous and hilly ranging between 381 and 488 meters but the highest peak reaches 500 m above sea level.

It has mean daytime temperature ranging between 24 and 30 °C and night temperature between 13 °C and 24 °C. Rainfall in the district is bimodal (with a mean value of 1,270 mm). The major rainy season usually comes between May and August and the minor peaks in October. The physical factors, especially geology and climate, have greatly influenced the demographic and economic activities in the district. According to the 2010 Population and Housing Census, Akuapem North District has a population of 136,483 (Ghana Statistical Service 2012). The population is composed of different ethnic groups dominated by the Twi- and Guan-speaking people as well as Ewes and Krobos settlers.

The less rocky nature of soils in the district and the relatively high annual rainfall totals (compared to the dry Accra plains) make farming very conducive. This might account for why majority of the inhabitants, especially those who live in rural communities within the district, are smallholder farmers. The main crops grown in the area are maize (*Zea mays*), yam (*Dioscorea* spp.), cassava (*Manihot esculenta*), plantain (*Musa species*), vegetables, and fruits. Few of the people are also engaged in the production of cocoa on small-scale basis. Nontraditional products such as mushrooms and snails are also produced to serve the nearby urban markets in Accra.

Methodology

Sixty (60) structured and open-ended questionnaires were directly administered to smallholder farmers from three communities in the Akuapem North District, namely, Adukrom, Akropong, and Bipoase. The questionnaires were structured into themes to capture respondents' background information (age, educational attainment, and sources of household income), knowledge and perception about climate variability and change, climatic and non-climatic factors that increase farmers' vulnerability, adaptive strategies, and the roles of public and private institutions in supporting climate change adaptation in the district.

The farmers who were interviewed were selected purposively and this was based on the size of their farms and long period of at least 10 more years of farming. A farm size of less than 0.4 ha (1 acre) to a little above 1.2 ha (3 acres) was established as a measure of a smallholder farmer. The technique was achieved by seeking advice from the local agriculture extension officers in the study communities who helped to identify smallholder farmers in their respective communities. Appointment was sought with each of the farmers who consented to participate in the survey.

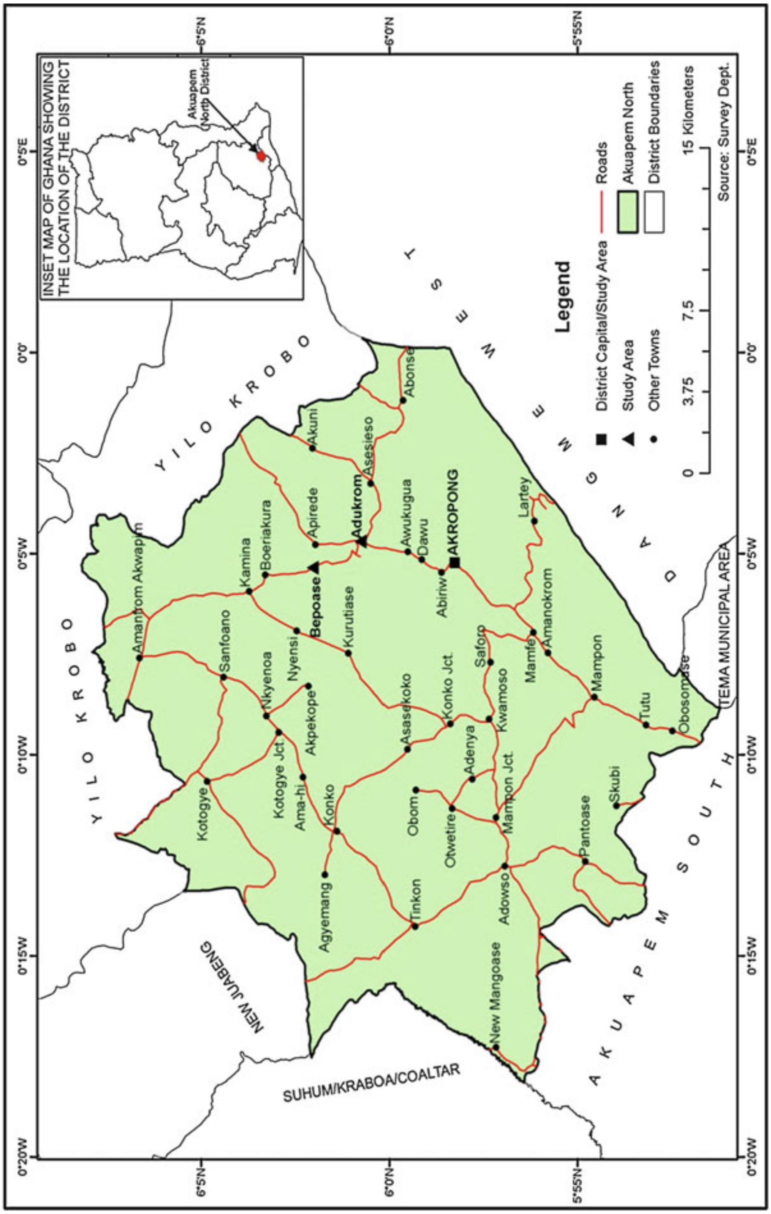

Fig. 2 Administrative map of Akuapem North District

Home visits were made to the farmers during which the questionnaires were administered. The researchers also visited few farms within the vicinities of the communities which provided them the opportunity to observe and understand some of the effects of climate change and adaptation practices of the farmers discussed in the interviews. The fieldwork lasted for a period of three (3) months. In all, twenty (20) respondents were interviewed from each of the three communities, adding up to a total of sixty (60) participants. Deliberate efforts were made to ensure that participants of different gender, age, and educational backgrounds were reached. Chi-square (χ^2) goodness of fit test was used to test the hypothesis that respondents' perceptions about causes of climate change differed across their socioeconomic characteristics. A significant level of 0.05 was used for the computation.

Daily rainfall data from 1965 to 2011 was obtained from the Ghana Meteorological Agency (GMet) for the Koforidua station to facilitate the analysis on the spatial pattern of rainfall amount and distribution in the district. The data were of high quality with only 3 years (1976, 1998, and 2005) having missing values and were therefore excluded from the analyses.

Data of total annual rainfall covering the 44 years between 1965 and 2011 were utilized. The 44 years were then divided into two 22-year periods as P1 (1965–1987) and P2 (1988–2011). The division was based on the acceptable notion that the pre-1980s were wetter periods than the post-1980s in West Africa (Owusu and Waylen 2009). The means and standard deviations were calculated for P1 and P2. In addition to the mean and standard deviation, changes in the variances and means of rainfall distribution for P1 and P2 were computed using F- and *t*-tests. The F-test was first performed to determine the appropriate type of *t*-test to be performed. From the F-test, it was indicated that the difference in variance between P1 and P2 was not statistically significant, shown by F $>$ F critical (2.23 $>$ 2.08). Based on the results, a *t*-test of two samples assuming equal variance at α value of 0.05 was tested using the formula:

$$\frac{T = \overline{\boldsymbol{Y}}_{\boldsymbol{1}} - \overline{\boldsymbol{Y}}_{\boldsymbol{2}}}{s_p\sqrt{1/\boldsymbol{N}_{\boldsymbol{1}} + 1/\boldsymbol{N}_{\boldsymbol{2}}}}$$

where N_1 and N_2 are the sample sizes for P1 and P2, $\overline{\boldsymbol{Y}}_{\boldsymbol{1}}$ and $\overline{\boldsymbol{Y}}_{\boldsymbol{2}}$ are the sample means, and ***sp*** is the pooled standard deviation.

Results and Discussion

General Characteristics of Respondents

In total, equal numbers of male and female smallholder farmers were interviewed. The average age of respondents from Bipoase was the highest (58 years) and the lowest occurred in Akropong (47 years). All the respondents have lived in their respective communities for more than 20 years and have at least 10 years of farming experience. Educational attainment of respondents in all the three communities is generally low and this reflects the general pattern of low education in rural Ghana

Table 1 Socioeconomic characteristics of respondents

Background characteristics	Percentage of respondents Adukrom (n = 20)	Akropong (n = 20)	Bipoase (n = 20)
Gender			
Male	55	45	50
Female	45	55	50
Total	100	100	100
Average age (years)	55	47	58
Average number of years of farming	15	17	23
Highest level of education			
No formal education	35	25	45
Primary	25	15	30
Middle school/JHS	15	30	10
Secondary school	15	25	5
Tertiary	10	5	10
Total	100	100	100
Household income (**source**)			
Average annual income from farm	GH $ 1,200	GH $ 1,500	GH $ 700
Average annual income from nonfarm	GH $ 500	GH $ 250	GH $ 400
Exchange rate 18 June, 2014: US$ 1 = GH $ 3			

(Ghana Statistical Service 2012). As already mentioned, the farmers interviewed practice subsistence system of agriculture. The farms serve two important roles: provide household source of food and income. The average annual household income from farm among respondents from Adukrom and Akropong was relatively higher (GH $ 1,200 and GH $ 1,500, respectively) than those from Bipoase because these communities have access to large market centers which enable farmers to sell some of their farm products. The respondents also get some proportion of their incomes from nonfarm sources, namely, petty trading, craftsmanship, and remittances (details shown in Table 1).

Farm Sizes and Type of Crops Cultivated

Farm sizes in the Akuapem North District are generally small with majority ranging between 0.4 ha (1 acre) and 1.2 ha (3 acres). This is attributed to many factors including the subsistence nature of farming and the complexities of land tenure system in the area as described by a cross section of the farmers who were interviewed. It was highlighted that farmlands are family owned and distributed among family members which results in land fragmentation. This does not promote mechanization or commercial farming. Table 2 shows the distribution of farm sizes of farmers interviewed during the survey.

Table 2 Average farm sizes of respondents interviewed from the three communities

Farm size (in hectares)	Location			Total ($N = 60$)
	Adukrom ($n = 20$)	Akropong ($n = 20$)	Bipoase ($n = 20$)	
Small (<0.4)	7 (35 %)	7 (35 %)	10 (50 %)	24 (40 %)
Average (0.8–1.2)	4 (20 %)	9 (45 %)	5 (25 %)	18 (30 %)
Large (>1.2)	9 (45 %)	4 (20 %)	5 (25 %)	18 (30 %)
Total	20 (100 %)	20(100 %)	20 (100 %)	60 (100 %)

A large proportion of farmers (40 %) had their farm sizes averaging less than 0.4 ha as against 30 % who also had their farm sizes ranging between 0.8 and 1.2 ha. Another 30 % of the farmers cultivate above 1.2 ha. These statistics on farm sizes of respondents give an indication of the subsistence nature of farming as alluded to earlier. In view of this, farmers within the three study communities are largely engaged in crop production as the main preoccupation is to feed themselves and their families. The findings indicate that maize (*Zea mays*), cassava (*Manihot esculenta*), plantain (*Musa species*), and vegetables like okra (*Abelmoschus esculentus*), tomatoes (*Lycopersicon esculentum*), and pepper (*Capsicum* spp.) dominate the type of crops cultivated by the farmers. It is, however, worth noting that majority of the farmers cultivated about two or three crops simultaneously between cassava, maize, plantain, and tomatoes. Also, all farming activities are rain-fed, meaning that any anomaly in rainfall amount or distribution could have significant impact on agricultural production in the district.

Smallholder Perception of Climate Variability and Change

The survey also shows that the participants have different knowledge and understanding about climate change. Respondents' knowledge, however, did not vary significantly ($p < 0.5$) across their age, level of education, and the number of years of farming experience. Some of the common attributes of climate change outlined by the respondents were excessive heat, drought conditions, irregular onset and cessation of rainfall, and too much rainfall. In terms of causes of climate change, wide variations of explanations were given by the respondents. According to 20 % of the respondents, climate change is due to deforestation and bushfires. Another 15 % believed that climate change is a sign of the end of the world. The majority of the respondents (50 %) associated climate change to the anger of ancestors. According to them, this is a vivid signal that "our ancestors do not like our modern way of life." The rest of 15 % attributed climate change to anthropogenic emission of greenhouse gases.

The responses of the farmers differed significantly ($p > 0.5$) according to their level of educational attainment and number of years of farming. All the farmers appreciated that the climate is really changing and this has affected agriculture. However, 85 % of the farmers who have long period of farming experience

(10 or more years) appreciated the phenomenon of climate variability and change as they were able to compare present climatic conditions with those that used to pertain over the past decades. The main climatic changes and variations these farmers stressed on were excessive heat, dryness, and too much rainfall leading to wilting of crops or even unable to till their lands. According to the farmers, beside rainfall variations and changes, temperatures have also increased, particularly, during the dry seasons in the last decade. The temperature increases perceived by the farmers are consistent with observations by Minia (2004) and Agyeman-Bonsu et al. (2008). According to Agyeman-Bonsu et al. (2008), temperature in Ghana has increased by 1 °C since 1960.

Realization of changes in rainfall was as a result of its unpredictable patterns during these few years, leading to high incidence of crop failures. The rain either delays than the expected time, lasts within a very short period during the planting season, or falls in torrent. All these have negative effects on agriculture production. To this end, it was necessary to compare the changes in rainfall over the years as recorded in the memories of the participants to the empirical rainfall data obtained from the GMet.

Statistical Analysis of Annual Rainfall Variability and Changes

The mean and standard deviation of annual rainfall totals were calculated for the two periods. P1 has mean of 1,373.9 and standard deviation of 256.6. And for P2, the mean and standard deviation are 1,340.7 and 171.8, respectively. It was determined that there has been a slight reduction in mean annual rainfall from P1 to P2. The 22-year average for P1 was 1,373.9 mm, while that of P2 was 1,340.9 mm. The standard deviation had, however, decreased from 256.6 in P1 to 171.8 in P2. This seems to imply that the rainfall in P2, even though low, is less variable on the year to year basis.

In order to confirm the observation made by the farmers that the frequency of dry spells has increased in the last two decades, the length of dry-spell days during the major rainy season from 1965 to 2011 was calculated using the statistical software Instat Plus version 3.36. Dry spells were defined as the number of consecutive non-rainy days after the start of the rainy season (Tadross et al. 2009; Ratan and Venugopal 2013).

Figure 3 shows that dry spell of 10 days or more are more frequent in P2 (1988–2011) as compared to P1 (1965–1987) which confirmed the observations made by the older farmers that rainfall frequency has slightly decreased in the last decades. The implications of these findings also support the long-known fact that annual rainfall totals have less agronomic significance than intra-seasonal variability. Before probing further into monthly analysis of the rainfall distribution, a test for statistical significances in the differences in means and standard deviation of the mean annual rainfall totals was made. The *t*-test indicates that the means of rainfall between P1 and P2 in Akuapem North District are not significantly different, shown by $t_{calc} < t_{table}$ (0.50 < 2.02) as illustrated by the means for the two periods although P2 shows a slight decline.

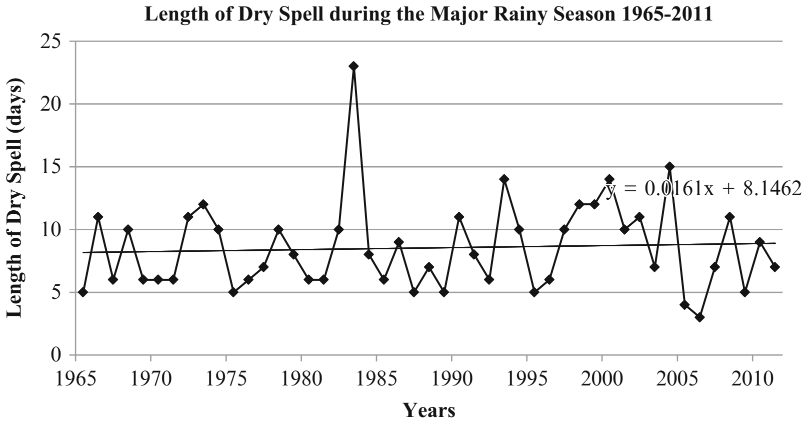

Fig. 3 Length of dry spell during the major rainy season

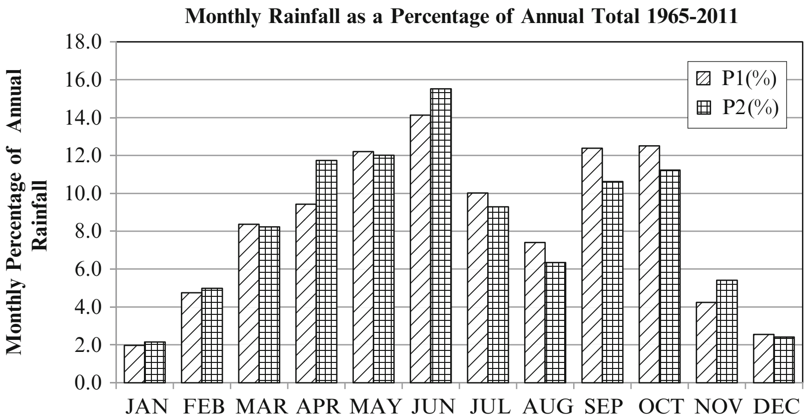

Fig. 4 Monthly rainfall total as percentages of the annual rainfall totals in P1 and P2

Guided by the farmers' assertion that rainfall has changed in the district resulting in crop failures and the fact that the annual rainfall total was not significantly different for the two periods, further probe was made to ascertain the rainfall distribution at the monthly level. The monthly rainfall total as percentages of the annual rainfall totals was calculated for the two 22-year periods as shown Fig. 4.

Figure 4 shows that rainfall distribution and amount in the district for P1 and P2 have mostly increased for the major rainy season, March to June in P2. The decrease in rains appears to occur in the minor season, July to August for P2. This pattern of minor season rainfall declines has been observed by Owusu and Waylen (2012) and by a cross section of the respondents who were interviewed from the three communities. Although the reduction has been very slight, the effects could be very crucial for agronomical activities by increasing crop failures during the minor rainy season in the district. This is because, unlike the major rainy season that spans a period of about 5 months, the bulk of rain in the minor rainy season only occurs in 2 months (September and October). The results of the monthly analysis seem to be in tandem with the views of older farmers in the study area that tie the high risk of crop failure in recent decades to changes in the rainfall regime rather than declines in the mean annual totals. The implication is that because produce from farms serves as the main source of household food and income, crop failure has significant adverse impacts on food security and household poverty in the study communities.

Non-climatic Factors That Make Smallholder Farmers Vulnerable

Apart from climatic factors of increasing temperatures and variation in the rainfall pattern, non-climatic but socioeconomic factors were also identified as major challenges impacting negatively on the smallholder farmers and making them vulnerable to climate variability and change. Notable among these factors are poverty and inadequate funds. According to the farmers, the most important constraint to their activities is inadequate capital to enable them pay for hired labor and buy fertilizers, pesticides, and other farming equipment. There are no banks or government agencies ready to loan money to the smallholder farmers in the district. As a result, they are unable to expand the sizes of their farms to increase production for home consumption and for the market due to land fragmentation and tenure complications. Another constraint they mentioned was scarcity of labor. According to the district migration data, emigration predominantly of the youth from the district has increased to more than 10 % since the past decades (Assan 2007; Akuapem North District Assembly 2012). The participants explained that most of the youth in the communities keep emigrating in search of greener pastures elsewhere in response to increased crop failure and loss.

A low price of farm products is another constraint that increases farmers' vulnerability to climate change and variability in the district. Sixty (60) percent of the farmers interviewed, predominantly those from Bipoase, explained that they do not have direct access to large market to sell their produce because of poor road transportation network and the higher cost they have to incur to convey their goods to the market. Instead, they trade directly with middlemen who come to them to do the buying, usually on the farm. These middlemen come with their own prices, which are very low, but since the farmers have no other alternatives, they accept the prices to prevent their products from going bad. The middlemen then sell the produce at very high prices in the urban markets. According to the farmers, although they do the hard work, they are the least profit beneficiaries. Less profit means they are unable to save some of their earning against unforeseen events. This problem together with those already discussed makes farmers less resilient and more vulnerable to climate change impacts, especially during prolonged drought or excessive rains leading to crop failures.

Strategies for Adaptation to Climate Change

The effects of climate change are likely to increase risk among smallholder farmers in Akuapem North District. According to the farmers interviewed, because climate change is a phenomenon that may persist for a long time, they have over the years put into place some measures that enable them cope and adapt to both adverse climatic and non-climatic stresses which increase their vulnerability. The adaptation practices are summarized in Table 3.

The most common adaptation practices are using indigenous planting techniques predominantly, doing watering, planting more resistant varieties of crops, and adjusting to rainfall variability, especially during the minor season. The farmers also engaged in on-farm activities like rearing of animals to supplement their household income, particularly during climate failures. Thirteen percent (13 %) of the farmers who have friends and relatives living outside the local community receive remittances to pay for labor and save some as a form of collateral against unexpected events. They, however, mentioned that such supports are sometimes unreliable because the amount and frequency of remittance depend on conditions in the source region.

Table 3 Frequency distribution of main adaptation strategies ($N = 60$)

Class of adaptation strategy	Specific adaptation practice	Frequency
Small-scale businesses	(i) Rearing of farm animals	10
	(ii) Sale of bushmeat and fruits	
	(iii) Making of gari, cassava dough, and palm oil	
	(iv) Engage in driving and carpentry work to supplement farm income	
Adjustment to variations in rains	(i) Diverting from farming activities and resuming when farming conditions become favorable	20
	(ii) Waiting for the rains to come before planting begins (late planting)	
	(iii) Early planting of seeds before rains	
Family support/ remittances	(i) Depending on family labor to carry out farm activities	8
	(ii) Depending on financial support of family members in the urban areas	
Indigenous methods	(i) Watering of plants such as tomatoes	22
	(ii) Planting of crop varieties more resistant to drought conditions	
	(iii) Rainfall harvesting for watering vegetables	
Total		**60**

Institutional Support for Climate Change Adaptation

In a typical rural setting like Akuapem North District, three major forms of institutions could be identified, namely, public, private, and civic institutions (Agrawal and Perrin 2008). In terms of public or government support, it was found out that although there are national climate adaptation strategies and programs, these have not trickled down to rural communities like Akropong, Adukrom, and Bipoase where the research was conducted. This is evident from the fact that there is presently no government policy intervention like sensitization and education program on climate change adaptation that can guide farmers to know what and when to plant in order to reduce the risk of climate failures. For instance, there are no seasonal forecasts given to the farmers during the cropping seasons. Farmers who were interviewed were ignorant of the existence of any national climate change adaptation program in the country. The farmers indicated that about a decade ago, the government used to distribute farm implements like cutlasses, hoes, and small funds for farmers in the district. However, these were not specifically to support climate change adaptation, but rather it was to help expand and sustain the breadbasket to reduce the risk of food insecurity in the district.

Also the farm materials and funds were not for free but have to be repaid in installment. For instance, at Akropong it was reported that some years ago, they received loans from the government in aid to boost up their production levels. Unfortunately, most farmers were unable to honor their debt because that year happened to be one of the most unfavorable farming years (high temperatures and low and sporadic rainfall). With such bitter memories, when respondents were asked if they will like to receive loans in the future, the majority were reluctant because of the fear of going through the same sour experience which will end them and their families up in jails because of inability to repay such loans.

At present, there is no private or civil society organization in the district that is into climate change adaptation to help the smallholder farmers. Similarly, none of the study communities has a civic institution like smallholder farmers' cooperatives that is focused on assisting members to cope in the event of crop failures due to variability and climate change.

Conclusion and Recommendations

In general, climate variability and change have adverse effects on smallholder farmers in Akuapem North District. Vulnerability and low resilience of farmers to climate variability and change impacts has been exacerbated by multiple non-climatic factors. Autonomous and reactive types of adaptation are the major strategies for adapting to the impacts of climate variability and change. So far, there have not been any planned and anticipatory types of adaptation assistance such as institutional support from the government, private businesses, and civil society organizations to help farmers in the district. The following are recommended to help reduce farmers' vulnerability and increase their resilience to the impacts of climate variability and change.

There is the need to strengthen their adaptation capacities mainly through institutional assistance in the form of government, NGOs, and cooperative bodies. These could help provide financial support to smallholder farmers to enable them adapt and increase output. The study, however, revealed that provision of loans for farmers to boost farming may not be successful because the farmers expressed their unwillingness to receive loans, citing past experiences and the possibility that crop failures could prevent them from paying back the loans.

Educating the farmers through outreach extension programs about climate change and its effects and cost-effective adaptive strategies such as water management would enable farmers cope with long periods of droughts and early rainfall cessations.

Also, there is the need to improve farmers' access to certain farming equipment like pumping machines, tractors, and spraying machines among others to help them increase their output within a short period of time. This will ensure that the scarcity and high cost of labor is substituted for by the farming equipment. A key strategy in achieving this goal will be through the formation of smallholder association.

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Dealing with Rainfall Variability for Food Production in the Nigerian Savannah

Grace Oloukoi, Mayowa Fasona, Felix Olorunfemi, Peter Elias, and Vide Adedayo

Contents

Abstract

The chapter investigates the observed and perceived trends and effects of rainfall on food production and identifies options that are adopted by farmers in dealing with the impacts in the Nigerian savannah. Data were sourced via community engagement, key informant interviews, and a survey of 191 farming households from 11 farm settlements in the region. Arithmetic monthly means of rainfall and temperature data from six meteorological stations within the ecological zones were used to generate the past and long-term trends of local climate. The study shows no significant variation of monthly mean rainfall

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across three decades of the observed data. However, there were similarities between the observed long-term averages of the station data and local perception that the amount of annual rainfall is decreasing, with delay in the onset of rain and increased trend of temperature. The variability impacts land-related livelihoods activities which are substantially tied to rain feeding. Annual planting seasons for cereals is changing from double to single, while harvest of tubers and nuts are gradually reducing. There are no organized adaptation frameworks, but when impacts are perceived by the farmers, coping ensued in the form of crop switch as on-farm modification and charcoal production as a form of off-farm livelihoods diversification. Available coping mechanisms are not adequate because they are leading to the ecosystem degradation. Local capacities need to be enhanced for improved food security and protection of ecosystems in the study area.

Keywords

Adaptation • On-farm modifications • Rainfall trends • Farming households • Nigerian savannah

Introduction

Global environmental change has the potential to alter water system in most regions of the world posing the challenges of water variability (IPCC 2008; 2012). Water variability is a phenomenon in which the available water supply is dwindling in terms of space, time, and quantity (IPCC 2007). It is often been influenced by precipitation, river runoff, other hydrological formation, population pressure, land-use and land-cover changes, and inadequate infrastructure (UNEP 2009; Easterling et al. 2007; MacDonald et al. 2009). Climate change and water variability, such as periods of drought and flood as well as longer-term change, may either directly or indirectly impact on all these three components in shaping food security: food availability, food access, and access to sufficient nutrients (Ziervogel et al. 2006).

African countries are probably worse off not only because of the reduction or mean variation in precipitation (MacDonald et al. 2009; Vörösmarty et al. 2005) but as a result of high poverty rates (Ellis 2000; Kurukulasuriya et al. 2006), disproportionate dependence on natural resource-based livelihoods, economies being highly dependent on rainfed agriculture, and significant limited adaptive capacity in terms of access to development resources (Adger 2006; van de Steeg et al. 2009). The population at risk of increased water stress in Africa is projected to be on an increase trend (Ashton 2002; FAO 2005) with about 75–250 million and 350–600 million people by the 2020s and 2050s, respectively (Arnell 2004; Nyong et al. 2007).

Coping refers to strategies that have evolved over time through peoples' long experience in dealing with known and understood natural variation that they expect in seasons combined with their specific responses to the season as it unfolds (IPCC 2001; Tompkins and Adger 2004). Coping with water shortages usually connotes temporary measures designed to maintain or return to the status quo (Wisner et al. 2004) which enables a society to function during changing circumstances (Kelly and Adger 2000). Coping also includes resilience development and flexibility (Fussel and Klein 2006), in terms of mobility, storage, diversification, and communal pooling (Halstead and O'Shea 1989).

In contrast, adaptive strategies refer to long-term (beyond a single season) techniques that are needed for people to respond to a new set of evolving conditions (biophysical, social, and economic) that they have not previously experienced (Adger 2006; Bigsten 1996). Adaptation is the process through which people reduce the adverse effects of climate and take advantage of the opportunities that their climatic environment provides, including all adjustments in behavior or economic structure that reduce the society's vulnerability. Adaptation options for farming livelihoods are subdivided into policy instruments; technological and structural measures; risk, sharing, and spreading; and change of land use (DWC 2006). Burton (1996) identified financial re-budgeting, behavioral change, on-site operation, market-based process, research, and education as elements necessary for adaptive capacity building.

In the sub-Saharan Africa, available coping strategies ensue as risks are perceived by local farmers. For example, off-farm diversification (Forum for Food Security in Southern Africa 2004; O'Laughlin 2002; Agrawal and Perrin 2008; Barrett et al. 2001), institutional architecture including rules and norms of governance (Osbahr et al. 2008), adjustments in farming operations (Bryceson 2004; Benhin 2006; Osman-Elasha et al. 2006), and social and economic capital networking (Rockström 2003 cited in Boko et al. 2007) are already identified.

In this chapter, emphasis is laid on precipitation as a key factor that affects water variability in the study area, because farming is basically rainfed. Coping and adaptation options are considered as strategies for dealing with water variability because some actions are based on long-term experiences while some evolved temporarily when water risks are perceived. Following the introduction, an overview of water variability and food production in Nigeria is presented. Then, a contextual analysis of coping and adaptation mechanisms that are adopted for food production in the Nigerian savannah as a case study is presented. Basic research questions include the following: What are the observed and perceived trends of local climate and how are these impact accesses to water for farming purposes? What types of coping and adaptation options are available and how are they being implemented by various actors? How may the adaptive capacity of the farmers be strengthened for improved food security?

Water Variability and Food Production in Nigeria

In Nigeria, rainfall pattern is based on the climatic and ecological grouping (Table 1). For instance, northeast Nigeria (a Sahel ecological zone) traditionally receives less than 400 mm total annual rainfall (Ayuba et al. 2007), southwest Nigeria (Guinea savannah) has had 1602.8 mm (Adeniji-Oloukoi et al. 2013), and

Table 1 Surveyed communities and household respondents

S/n	State	LGAs	Communities	[a]Population (1991)	[b]Population (2012)	No of selected household respondents	Percent of respondents to total respondents
1	Kwara	Ifelodun	Yaaru	1,222	1,961	22	11.5
2	Kwara	Ifelodun	Idofian	5,519	8,857	16	8.3
3	Kwara	Irepodun	Agbonda	1,030	1,653	13	6.8
4	Oyo	Surulere	Orile-Igbon	219	351	14	7.3
5	Oyo	Saki East	Sepeteri	12,317	19,766	22	11.5
6	Oyo	Iwajowa	Iganna	17,666	28,350	17	8.9
7	Oyo	Orelope	Igboho	38,871	62,380	19	9.9
8	Oyo	Olorunsogo	Dogo	450	722	10	5.2
9	Oyo	Itesiwaju	Ipapo	5,962	9,568	19	9.9
10	Oyo	Orire	Ikoyi-Ile	3,328	5,341	23	12.0
11	Oyo	Atisbo	Baasi	541	868	16	8.3
Total				**87,125**	**139,817**	**191**	**100.0**

[a]NPC, 1991; [b]Estimates based on 2.83 annual growth rate

southeast and south-south (rainforest and fresh water swamp, the Deltas) receive 1,800 mm (Gbuyiro and Adefisan 2007). Ayoade (1995) and Adejuwon (2008, 2012) also indicate that rainfall is more variable during the dry season from November to April than during wet season which runs from May to October over most parts of Nigeria. Precipitation variations in the distribution of annual and seasonal rainfall are accounted for mainly by the Inter-tropical Discontinuity (ITD) (Ayoade 2003; Fasona et al 2011). Annual rainfall variability is highest in the north and least in the southeastern parts of the country and moderately high in the southwest (Mehrotra et al. 2009).

In relation to temperature, Adejuwon (2006a) indicates that across the various climatic and ecological zones in Nigeria, maximum temperature varies between 28 °C and 40 °C. In coastal locations, maximum temperatures are lowest in August at about 28°and highest in March to May (MAM) at around 34 °C. In the subhumid Guinea zones, maximum temperatures are also lowest in August at about 30 °C and highest in the MAM season averaging 38 °C. In the semiarid zone, the highest maximum temperature as high as 40 °C is also recorded during the MAM season. On the other hand, the lowest maximum temperatures of around 28 °C are experienced in December or January.

A recent assessment of the vulnerability of agriculture to climate change in Nigeria using different General Circulation Models (GCMs) indicated that temperature changes will adversely affect sorghum production in the north. Reduction of rainfall in the southern parts of the country could adversely affect the rainforests and the yields of tree crops such as palm oil, cocoa, and rubber. Given the likely shift in vegetation patterns, the areas of concentration of the production of livestock, especially cattle, sheep, and goats, may be particularly affected by the increase in rainfall shown by the CNRM-CM3 and the MIROC 3.2 medium-resolution GCMs. In the same assessment, increasing rainfall could support the production of fodder crops but could also create favorable conditions for the proliferation of animal diseases and pests (Shuaib et al. 2013).

In Nigeria, societies have adapted to water variability in an evolutionary way through the development and use of systems; mechanisms by individuals, households, and communities to move on with their lives; and getting used to existing water variability and stress (Adejuwon 2006b, 2008; Adejuwon et al. 2007; Nyong and Kanaroglou 2001). In the Sudano-Sahel region in Nigeria, Adesina and Odekunle (2011) identify socio-reengineering (behavioral shifts) and recharging of wetlands. In the southwest, expansion of irrigation infrastructure and adoption of indigenous conservation of water resources are common (Gbadegesin and Olorunfemi 2011). Shifting towards more heat-tolerant or water-loving crops as seasons change is mostly adopted in all regions (Adejuwon 2012). In terms of policy design, some arrays of adaptation are mainstreamed into agricultural and environmental policies at the national level. The challenge is that most of the policies are generalized models which had not taken cognizes of specific local context especially in marginalized arable farming communities.

In Nigeria, coping with water variability for food production is also mostly autonomous because actions are implemented by individual farmers, rural communities, and/or farmers' organizations, depending on perceived or real climate change and without external intervention. In essence, coping strategies ensue as risks to farming activities are perceived by local farmers. It is therefore important to identify specific coping mechanisms that are already in use in local communities of the Nigerian savannah where the primary livelihoods activities are tied to rainfed farming.

Dealing with Water Variability: Case Study of the Nigerian Savannah

Data and Methods

The Study Area

The study area is located within latitudes 8–9°15′ north and longitudes 3°50′–5°50′ east, covering an estimated 40,000 km^2 in parts of Oyo, Kwara, Kogi, and Niger States in west-central Nigeria (Fig. 1). Soils consist of deep, well-drained, sandy loam soils in large areas and poorly drained sandy clay loam subsoil along the Niger floodplain. It lies within the vegetation belt described as the wooded savannah, a transitional zone between the southern rainforest and the tropical guinea savannah vegetation belts in Nigeria. In recent time, the region experiences environmental degradation as a result of population pressure, decreasing of woodlands, deforestation activities, and land-use and land-cover change (Akinbami et al. 2003).

The climate is characterized by a subhumid (*e*quatorial savannah with dry winter) where minimum precipitation is less than 60 mm in winter (Kottek et al. 2006). Annual rainfall lies between 900 mm and 1,300 mm. The area experienced a slightly bimodal rainfall pattern. The highest monthly rainfall occurs in September as opposed to July for the southern rainforest belt. Maximum temperature range is between 28 °C and 36 °C with February/March being the hottest months and the lowest maximum temperature experienced in August. Rainfall is the most important climatic factor critical to human survival. Both the mesoscale and large-scale processes define about 75 % of factors of rainfall characteristics of the savannah (Omotosho and Abiodun 2007) with impacts on regional water footprint and local livelihoods because of the prevalence of rainfed farming system (Fasona et al. 2011). Other anomalies that have been studied indicated the occurrence of double peak periods within the wooded savannah region (Adeniji-Oloukoi et al. 2013; Gbuyiro and Adefisan 2007). The future climate projection suggests an increase in temperature and decrease in the annual rainfall amount in the area (Abiodun et al. 2012).

In terms of livelihoods, human activities are agro-based in the form of rainfed farming, forestry, hunting, herbs and seeds collection, and food processing because the region is dominated with rural communities. The region's rich and large pasture undergrowth has made the area an important extensive grazing area for migrating agropastoralists from the drier Sahel and Sudan zones of the savannah (Fasona and Omojola 2005; Adisa and Adekunle 2010).

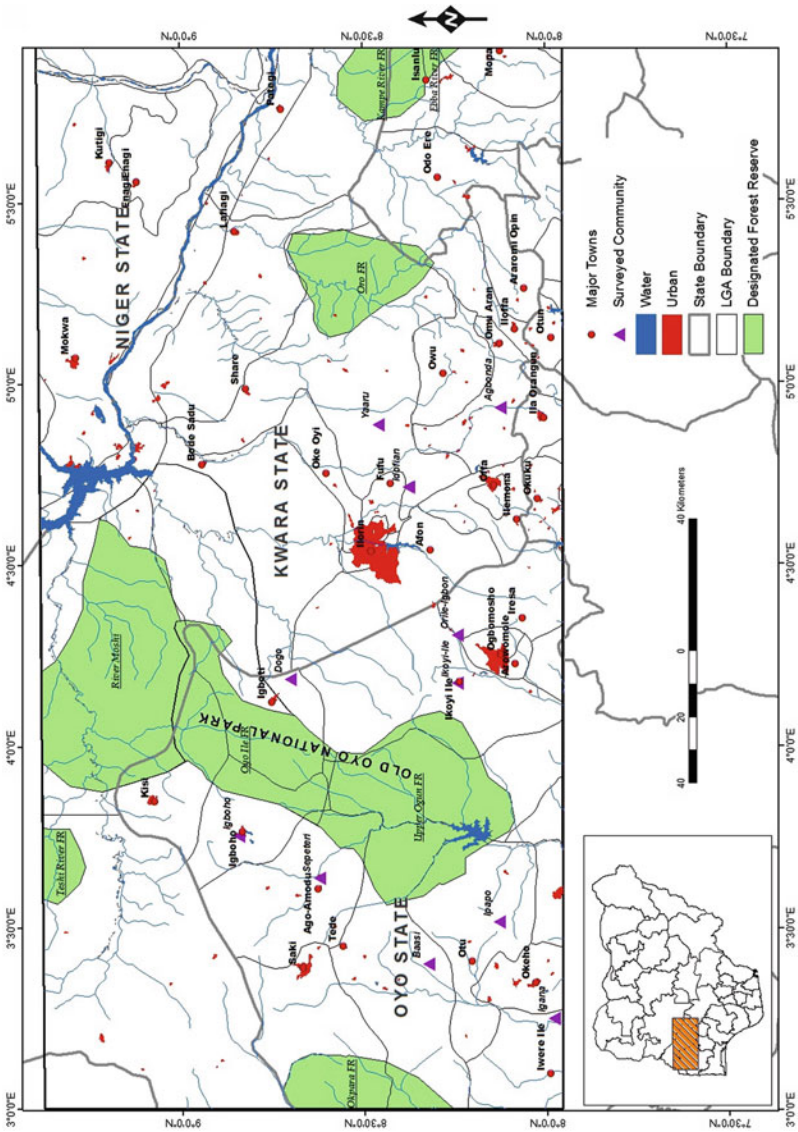

Fig. 1 Study area

Data Sources

This chapter captures a part of the project on “community-based management of ecosystem and natural resources for improved food security in the Nigerian savannah” with a research framework and procedure for data capturing, analysis, and synthesis of observation were thus followed:

Document Review and Development of Conceptual Framework

Various documents including policies, programs and projects were reviewed with a view to familiarizing with what the situation with regard to ecosystem management, livelihood, agriculture and food security, and climate change and the nexus or interconnections among them.

Climate Data

Recent rainfall and maximum temperature data were obtained from the archive of the Nigerian Meteorological Agency (NIMET) to cover the six stations around the study area. The arithmetic monthly means from the six stations were analyzed for decadal trend with the view to examine if there has been any significant shift in the temporal pattern over the three-decade period (1982–2011).

Base Maps

The spatial databases acquired include the following:

- Analogue 1:50,000 topographical map sheets were used as the guide to extract place names and location of communities. Information extracted was compared and updated with other existing sources of place names.
- Digital version of the vegetation and land use maps was produced by the then Forestry Management, Evaluation and Coordination Unit (FORMECU) of the Federal Ministry of Agriculture and Natural Resources for 1976 and 1995 at 1:250,000 scale.

These maps were used for the reconnaissance work estimate hot spots of vegetal changes and to select communities that are within 5 km radius of any forested area for fieldwork.

Pilot Surveys

There are over 2000 communities within the study area. The multistage stratified random sampling was adopted. The first stage was to set certain criteria that a candidate community must satisfy. The conditions are:

- The community must not be more than 5 km away from a forested land – this makes it easy to connect livelihood to forest and farm land.
- The community must be a rural or semi-urban – this is based on the assumption that the natural resource capital is more important to livelihood and food security in rural and semi-urban areas than urban areas.
- Two communities to be selected from each local government area (LGA).

Two states (Oyo and Kwara) constitute about 80 % of the entire study area. Then, a list of all the LGAs and communities in the two states was made. Using data generated from preliminary Geographic Information System (GIS) assessment, 44 communities across 21 LGAs in 2 States were selected and the tentative sample size was to be 25 households in each community.

The purpose of the pilot fieldwork was basically to:

- Conduct a reconnaissance of the general and specific ecologies
- Test the field instruments
- Establish a contact with community and opinion leaders and other stakeholders

From this preliminary list, the study area was stratified into three longitudinal zones; communities selected in each zone about 80 km to 100 km apart were covered in the pilot survey. The pilot survey was carried on the 28th and 29th of December 2011.

The pilot survey reveals that the general ecology and socioeconomic and demographic profile including livelihoods in all the communities are very similar. Based on these considerations, the number of communities where the final survey was done was narrowed to 11 which were drawn across the three stratified zones. Other consideration include possible past or present engagement or involvement with any state government poverty reduction and sustainable food production initiatives and nongovernmental projects such as the Local Empowerment and Environmental Management Project (LEEMP) and the Fadama were taken into consideration in selecting the communities for the final survey.

Designing the Survey Instruments

The primary data were collected using field observations, administration of questionnaires, and structured interviews. Three sets of questionnaires were designed for selected households, key informants/focused groups, and government (local and state government) offices in charge of natural resources, environment, agriculture, forestry, and other related agencies. The questionnaires were designed to include questions on livelihood and access to resources, perception on trends and impacts of climate change and water variability, adaptation options, and adaptive capacity.

Household Survey

Eleven communities spread across nine LGAs in two states (six in Oyo and three in Kwara) participated in the final survey (Table 1). The sample size for the study was further refined after the pilot survey with the total number of community narrowed to 11 communities with 191 households. The final survey was completed in February 2012. An adult member of selected households was the respondent for the household survey. Based on the established criteria for the selection of the sampled communities for the social survey, it should be noted that these communities were not the same with the local areas with meteorological stations whose climate data were used in this study.

Focus Group and Key Informants

The investigators engaged community leaders, i.e., traditional rulers and opinion leaders (who are traditional title holders) in key informant interview. Leaders and members of community association and groups were engaged in focus group discussion. Investigators also engaged with officers in charge of agriculture, forestry, and other related agencies at the LGA and state levels. Information elicited include the capacity and resources available for coping during water variability, reports on food insecurity, and willingness to partner and encourage local community participation in adaptation and mitigation planning.

Another engagement with the stakeholders was done in May 2012, during a workshop in which the major findings of the research project were discussed. This activity in particular provided opportunity for feedbacks and inauguration of a network named, ECOVANGUARD NIGERIA (www.ecovanguardnigeria.com).

Analysis of Social Survey Data

The questionnaire for household and LGAs was coded and analyzed to descriptive information. FGD and key informant interviews were transcribed from audio and video which were discussed under thematic issues.

Result and Discussion

Sociodemographic Profile of Study Population

The demographic analysis suggests that 78.3 % of the respondents were married, 15.5 % were single, and 6.2 % were widowed/or separated. The survey captured the ages of the active group (83.7 %) of the population in which ages between 31 and 45 accounted for 40.3 %, ages 18–30 accounted for 20.9 %, and ages 46–60 accounted for 22.55 %. The study area is characterized by large household sizes. Household size of between 4 and 7 persons accounted for 38 %, and those between 8 and 11 persons were 29 %. Only 17 % had household smaller than 4. One reason for preference large household might be the large number of children. It is a general assumption that children are expected to help their parents on the farm. Although the people are predominantly of the Yoruba tribe of southwestern Nigeria, labor migrant population from other ethnic groups including Agatu from Benue State across the Niger (9.9 %), Ibo from the southeastern states (1.6 %), and the Hausa/ Fulani from the northern Nigeria (2.6 %).

Livelihoods and Income Profile

Primary livelihood activities in the study area are substantially tied to farming and other natural resource systems (Fig. 2). From the survey, 62.2 % of the respondents indicated that male plays the most prominent role in farm produce, compared to only 3.9 % female. This result is contextual, because within the western region of Nigeria, activities such as small-holder farming, cutting of tree for firewood, or charcoal processing are physically tedious; hence, they are male dominated. The agroecological characteristics of the area considerably favor root and tuber crop cultivation.

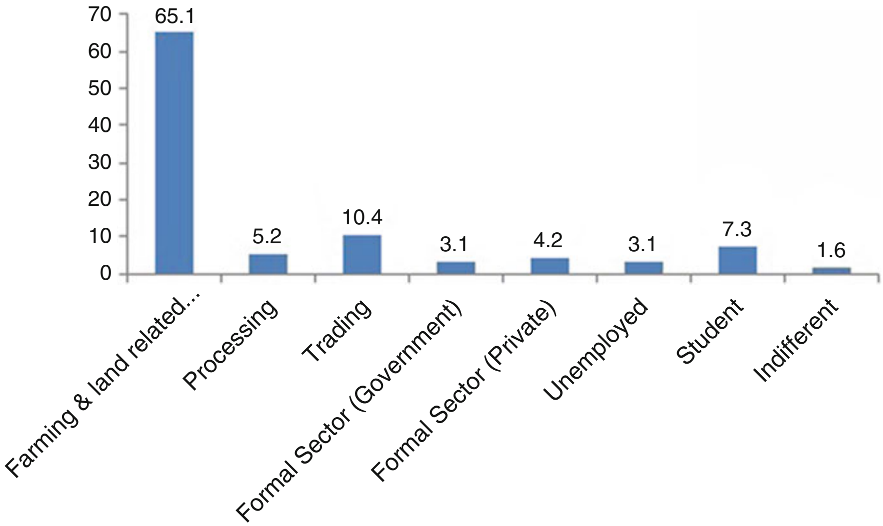

Fig. 2 Primary livelihoods in the study communities

Farming methods include mixed farming, rotation of crops, and shifting cultivation. A key issue from observation from the field individual acreage holding is small, and the yield per acre is often very low because modern farming inputs are not used, not available, or cannot be accessed by these peasant farmers. Women are also engaged in livestock keeping, vegetable farming, and water and firewood collection basically for households' nutritional needs and not for commercial purpose. Both the focus group discussion (FGD) and the key informant interview (KII) with the LGA officials and traditional rulers indicated that men and women have equal right to land ownership.

Other major livelihood activities are agro-based processing and woodland resource collection. Most (48 %) women do forest and woodland resources collection (e.g., orange, mango, wore nuts, and seed gathering (e.g., palm kernel, cashew), fuel wood and leaf collection for sale, and petty trading of basic daily needs and food items. Small scale agro-based processing includes cassava processing to *garri* (cassava flour (*sun-dried and ground* cassava) which is the commonest staple food in Nigeria. *Igba* seeds were processed from *Parkia biglobosa* to *Iru* (locust bean), *Emi* seeds from *Vitellaria paradoxa* to *Ori* (shea butter), yam to *elubo (*yam flour), and wood ash to local (black) soap.

Secondary livelihood activities are the short-term off-season activities which the rural communities engaged in for supplementary income generation. A significant number (48 %) of people (especially the youth) work at construction sites as casual laborers for charcoal production and commercial cycling especially during dry season.

The income profile shows that over 70 % earn or generate a maximum of N30,000 (less than $200) every month from their primary livelihood activities. This suggests that majority of the population are peasant farmers who can be classified as poor. It was also observed that no books are kept for income and

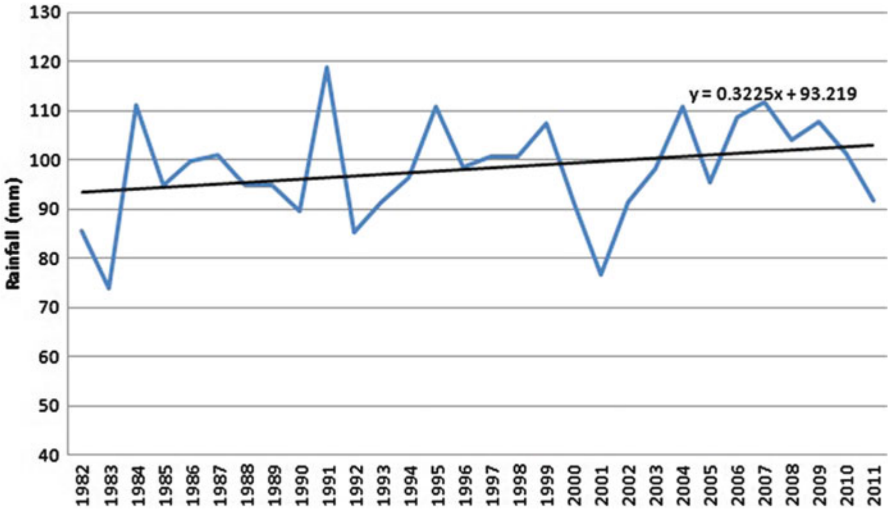

Fig. 3 Trend of annual mean rainfall (1982–2011)

expenditure (at least by majority of the farmers). This makes it extremely difficult for them to actually know how much they make as income from the farm.

Climate Variability in the Nigerian Savannah

Observed Rainfall Trends

The long-term trend in the monthly mean rainfall data (averages from the six stations) suggests that rainfall amount is increasing marginally (about 3.2 mm per decade). This is in contrast to the belief of the local people that the amount of rainfall has been declining. Figure 3 shows the observed trend of annual mean rainfall across the study area.

However, since about 75 % of rainfall in the savannah depends on mesoscale processes, the station data may not have adequately captured the true situation in the communities. This may be so because these stations are more than 100 km from each other and may not effectively capture the effect of local climate processes around the communities.

To determine the rainfall variability in the study area during the three decades (30 years series), the paired sample *t* test was used. Based on the paired *t test*, the result in Table 2 suggests that there are no statistical significant variations in the monthly mean rainfall between the three decades (i.e., 1982–1991, 1992–2001, and 2002–2011) in the study area. Even though the statistical test does not reveal a significant variation, comparisons of the trend in each decade compared with the long-term mean (Fig. 4) suggest a shift in the temporal pattern of rainfall that is consistent with the beliefs of the people in the study area. For example, the decade 1980–1990 was a drought one, while the decade 1990–2000 displays a clear dual peak pattern with peaks in June and

Table 2 Comparison of the mean (paired sample test) for the three decades monthly mean rainfall trend

		Paired differences							
					95 % Confidence interval of the difference				
		Mean	Std. deviation	Std. error mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Decades 1982–1991 and 1992–2001	−3.7684E0	1.2332E1	3.5601E0	−1.1604E1	4.0673E0	−1.059	11	.313
Pair 2	Decades 1992–2001 and 2002–2011	−1.15646E0	1.1793E1	3.4046E0	−8.6499E0	6.3370E0	−.340	11	.740
Pair 3	Decades 1982–1991 and 2002–2011	−4.9249E0	1.4341E1	4.1400E0	−1.4037E1	4.1871E0	−1.190	11	.259

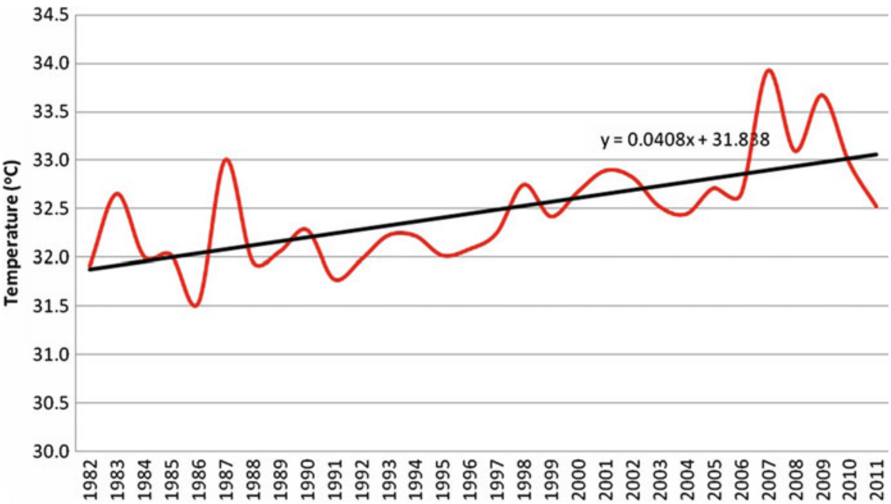

Fig. 4 Monthly mean temporal pattern of rainfall over three decades compared with the long-term mean

September, and the decade 2000–2011 displays only one clear peak that occurs in September. The gradient of rainfall in the decade 2000–2011 was also higher than normal distribution which suggests later onset of the rains and early cessation that is consistent with the perceptions on rainfall by the people.

Observed Temperature Trend

The observed trend of the mean maximum temperature is positive which suggests warming trend (Fig. 5). In all the stations in the study area, the mean decadal temperature has been rising from 1982–1992 to 2001–2011 decades (Fig. 6). Two stations (Bida and Lokoja) indicated higher temperature than the other four stations during the three decades.

Perceived Rainfall Trends

Perceptions are often used for vulnerability assessment in order to integrate social dimension of risks impacts through local engagement. It is not only the participants' responses that are important but also how they respond, what they affirm, and the tones of their affirmation (Sullivan 2010). In the study area, perceptions based on social survey suggest that the populations are aware of variability of climate parameters and its implications on farming livelihoods. Analysis of the households' survey shows that 94 % believes that there have been changes in the patterns of rainfall. Comparing the present rainfall trends with that of the last 10 years (decade before 2002–2011), majority (60 %) believes that rainfall has been decreasing (Fig. 7).

Generally, higher percentages of the sampled farming households in the study area were of the opinion that annual rainfall trends in terms of onset, cessation, and length of growing season are decreasing (Table 3). The perception of annual

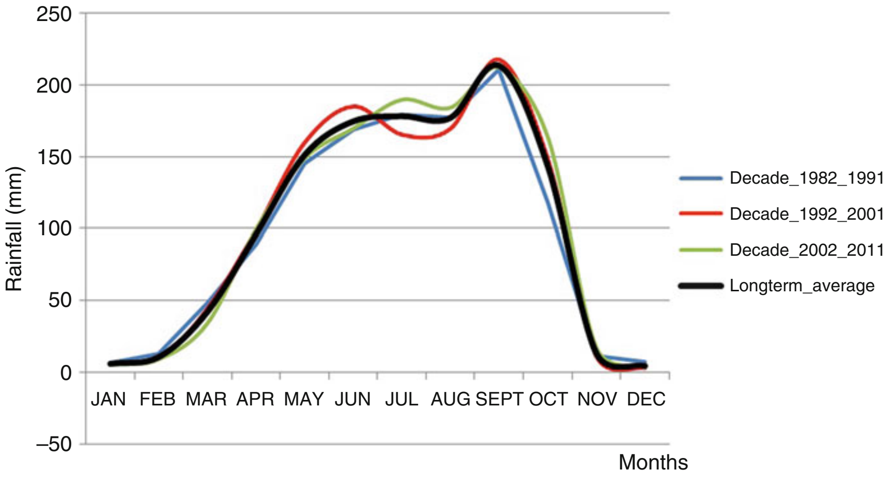

Fig. 5 Trend of mean monthly maximum temperature (1982–2011)

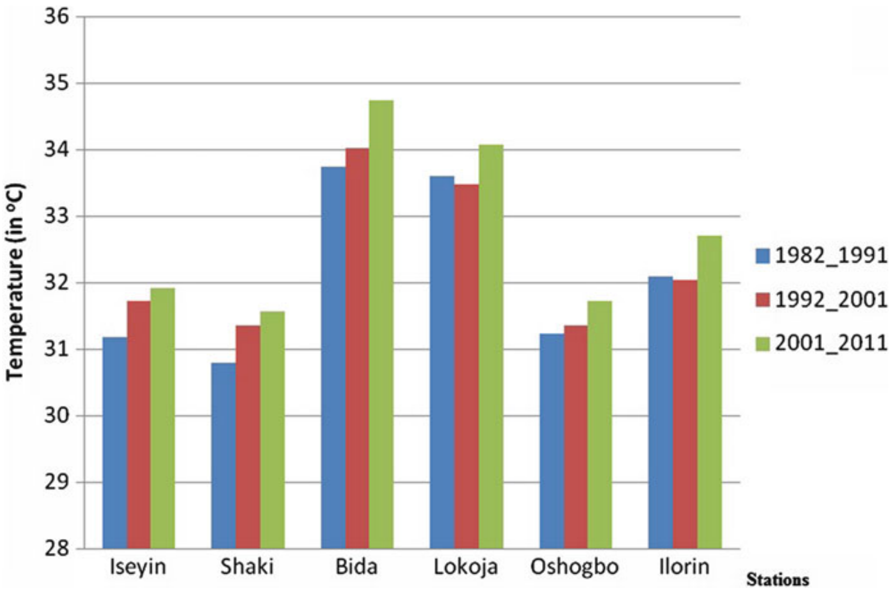

Fig. 6 Mean decadal maximum temperature for selected stations in the Nigerian wooded savanna

rainfall across the communities is shown on Fig. 8. In all the communities except Orile-Igbon, the overwhelming response is that annual rainfall amount has been decreasing compared to some 10 years ago (decade before 2002–2011). Perception on number of rainy days, onset and cessation of the rains, onset of the growing season, and length of the growing season in recent time compared to 10 years ago indicate that over one-third of the population perceived that there has been a

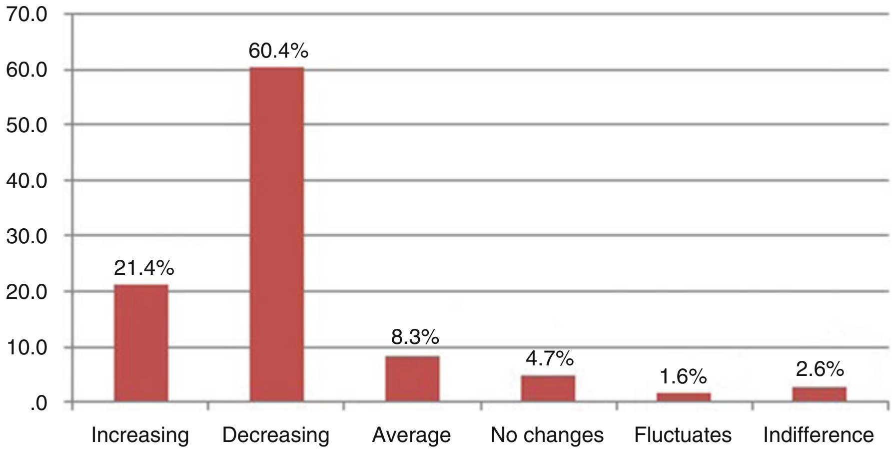

Fig. 7 Farmers' perception (in percentage) of annual rainfall compared to 10 years ago (before 2002–2011)

Table 3 Farmers' perception on number of rainy days and onset and cessation of the rains (in percent)

Number of rainy days	Rainy days $N = 191$	Onset of rain $N = 191$	Cessation of rain $N = 191$	Onset on growing season $N = 191$	Length of the growing season $N = 191$
Increasing	13	3.6	4.2	1.6	0.5
Decreasing	37.5	37.5	33.9	34.9	39.5
Average	16.1	26.0	24.9	21.4	18.8
Below average	0.5	3.6	2.6	2.1	1.6
Above average	1.6	0.5	1.6	1.0	1.0
No changes	7.8	7.3	9.9	14.1	12.0
Fluctuates	6.3	10.9	10.4	11.5	12.0
Indifferent	17.2	9.4	12.0	12.5	13.6

decline in all these variables. This has implications for small-holder rainfed agriculture on which rural livelihood thrives.

In terms of the number of hot days in recent times compared to 10 years ago (i.e., decade before 2002–2011), 42.7 % believes hot days are increasing, and 14 % thinks it is decreasing (especially as regards implication for farming). Correspondingly, 27.1 % believes cold days (i.e., days of lowest daytime temperature normally experienced during the rainy season in June–October with August being the coldest month) and during the harmattan season (December–January) are decreasing. 15.1 % believes it has been increasing, while 18.2 % thinks there has been no considerable change and 8.9 % thinks there has been fluctuation. Figure 9 shows the perception of temperature compared to 10 years ago across the communities.

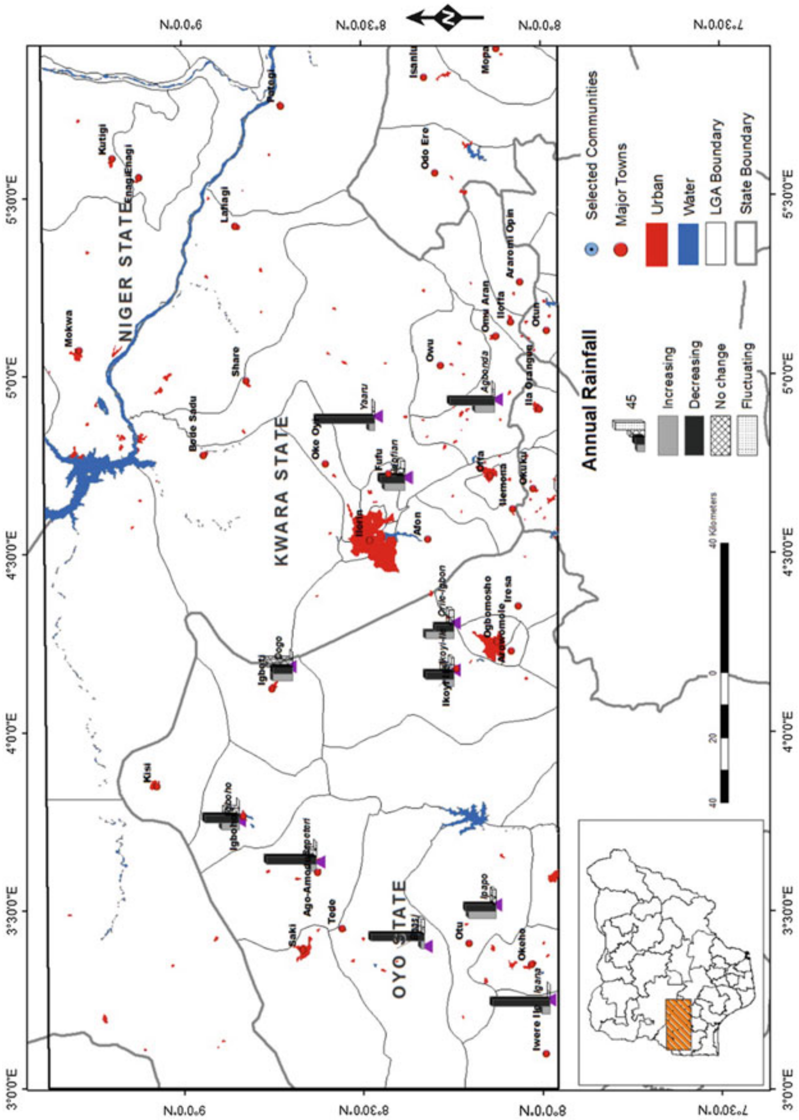

Fig. 8 Farmers' perception on the trend of annual rainfall across communities

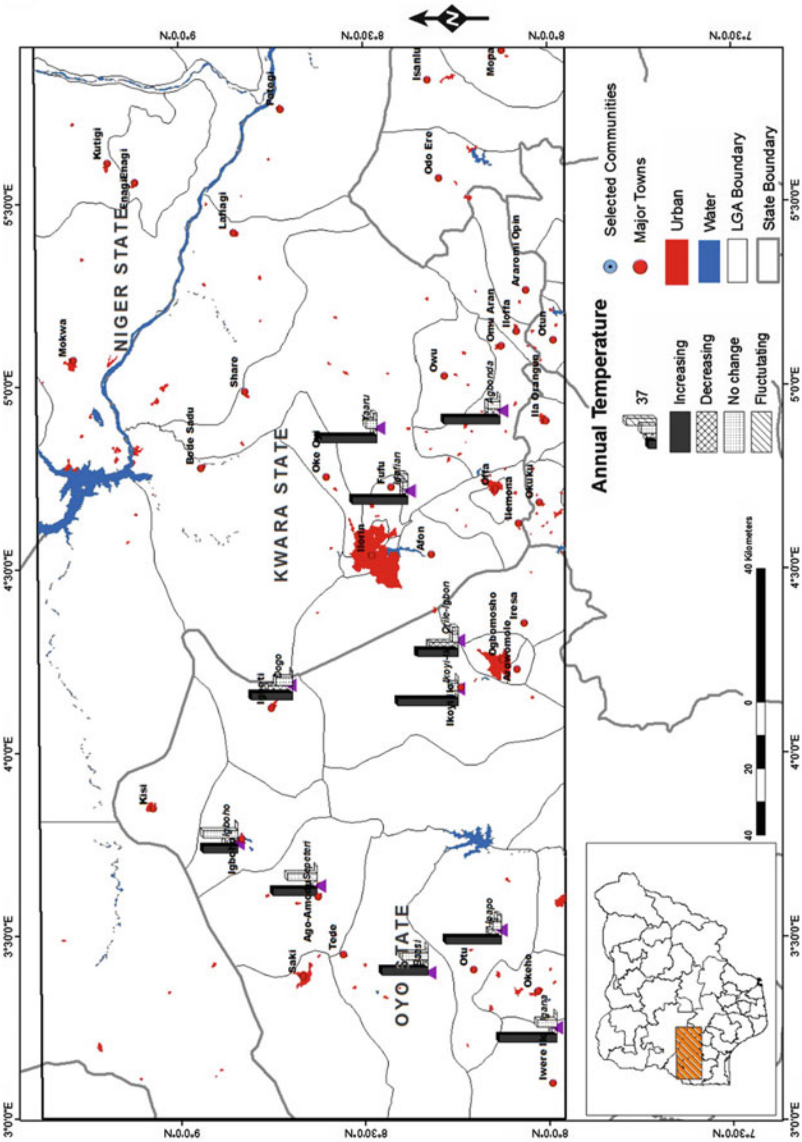

Fig. 9 Farmers' perception of annual temperature compared to 10 years ago across the communities

Voices of Community Leaders on Trends and Impact of Rainfall Variability

Engagement with traditional rulers and other key informants in selected communities affirms that there has been a reduction in the number of rainy days and the frequency and intensity rains during the wet season. Although there are no existing agricultural data to compare with perceptions on onset and cessation of the growing periods, perception related by the community leaders (Box 1) suggests that farming livelihoods are already being impacted.

Box 1: Voices of Community Leaders on Impacts of Rainfall Trends on Farming Livelihoods

The pattern (of climate) has changed. The climatic factors and elements have changed. Rainfall pattern has also changed. One thing that I know is that the local cause here is the falling of trees, and that is why we want to stop them from cutting our trees.

Last year, rain started in March and stopped in April at the time we were preparing for planting. We eventually had late planting. By the end of October, the rain ceased. This occurrence led to a massive crop failure that most farmers complained bitterly. In case we had much rain and crops are not yet ripe for harvest, it will bring crop failure. So the effect is that our planting period is changing as the weather condition changes which is not easy to adjust to.

– The traditional ruler of Iganna

So far, the weather condition has changed compared to the previous years. Back then, we grow our maize in the third month, and by the fifth cassava will be on our farms, but now we usually see rain in the fifth month and it will not last a long period before it ceases.

– The chairman of Community Development Association of Sepeteri

Since I moved into my town from Lagos, the rains have been reducing in the past 6 years. Some of the flowing rivers are drying up. If you look at this part of Kwara Stat, our rainy season is not like the other parts that receive more rainfall during the wet season.

– The Yaaru community leader

Last year was not too good for us in terms of rainfall. We expect rain in its the normal period but it failed. In fact, some of us had the problem of crop failure. Then, we pray that the following year be better than the previous year in which our target will be to make all the likely profits.

– The Aare-Ago (High Chief) of Igboho

When onset of rain is delayed, it affects our crops. About 8 years ago, the rain stopped too early; we were unable to make ridges for the yam. The heat is too much now. Last year, rain started very early and it stopped very early. We normally change the type of crops we plant once the season is altered. We used to have two planting seasons in a year, but now it is once in a year.

– The community head of Baasi

Coping Strategies

Coping strategies being adopted by local farmers towards improved food production are categorized based on on-farm and off-farm options. The on-farm options are activities carried out directly on the farm plots during the growing seasons: preplanting, planting and post planting, while off-farm deals with activities that are done outside the farm plot including behavioral shifts and livelihood diversification (Table 4).

On-Farm Modification Activities

Preplanting Season

Farmers know the implication of timely planting. The dry season is used to prepare the land for cultivation before the onset of rain. The method of land preparation for farming is one of those means through which forests and woodlands are removed, usually in December, January, and February (DJF). The study shows that about 80 % adopt forest burning system as the traditional practice for land rejuvenation. The explanations for choosing this method are as follows: the method is better than any other method (27 %) and it is traditional (11.5 %) with an assumption that the ash produced by burning goes back to the soil as a form of (organic) manure to enrich the soil and improve soil fertility. Additionally, 38 % believes these farming practices have no negative effect on the environment, while 22 % are indifferent.

This land preparation has implication for early crop production especially if there is no delay in the onset of rain. Farmers that are favored with early planting might also enjoy higher productivity and better market price especially during new crop harvest as in the case of maize, vegetables, and yam. In case of false onset of rain, such early planting might result into crop failure. While bush burning may serve as land preparation, it also destroys soil organisms, specific habitats, and plant communities. In several instances, the fire often extends beyond the original intended lands and spreads into other areas thereby causing several ecosystem perturbation that may take several years to recover.

Planting Season

The study suggests that during planting season, at least one of or all of irrigation, application organic manure, and rain harvesting are adopted by at least 60 % of the farmers. About 17.7 % also now hire laborers to assist them in farm works. Evidences from the field show that in majority of the farmers rely on inland wetlands (Fadama) along seasonal streams. Some farmers adopt application of fertilizer to grow crops during the dry season especially in Iganna and Idofian communities. In relation to cropping system, most farmers adopt mixed cropping and shift cultivation.

Mulching: this practice helps to protect seedlings against dry spells during the earlier parts of the growing season. This is usually applicable to tubers such as yam and cocoyam. During planting, the yam seeds are first covered with top soil, and then the green or dry leaves are arranged to cover the top soil against

Table 4 Categories of coping and adaptation strategies in dealing with water variability

Location	Period/season	Strategies
On-farm	Preplanting	Land preparation: bush clearing and burning
		Shift cultivation
	Planting	Delay tactics by watching false onset of rain
		Mixed cropping
		Mixed farming (crop and livestock keeping)
		Crop rotation
		Crop shifting and modification
		Mulching
		Application of fertilizers
		Use of laborers to assist with hand pump irrigation
		Use watershed for irrigation (e.g., Fadama)
	Post planting	Late harvest (harvest period is delayed)
Off-farm	All seasons and especially during crop failure	Livelihood modification: engagement in alternative income-generating activities such as farming plus trading, vegetable gardening, food processing, etc.
		Livelihood diversification: charcoal production, collection of firewood, leaves, herbs, and other woodland resources
		Migration to cities for paid labor
		Engagement in other sources of income like commercial motor cycle transportation (*Okada*)
	Dry season	Protection of watersheds
		Demarcation of different water sources for different uses
		Water reuse especially during food processing (e.g., cassava flour)
		Behavioral shift by reducing volume of water used for some activities
		Rainwater harvest and storage especially for domestic uses
	Long dryness/drought	Appealing to farm goddess (*Orisa Oko*)

the scorch of the sun. This is important to further reduce evapotranspiration of water that yam planting is usually done around October to December (at the cessation of rain).

Mixed cropping system: more than one crop is planted at a time or at intervals throughout the growing season, and it is the most preferred farming system. To do this, most farmers plant legumes and cereals or tuber and cereal together on the same plot with the aim to maximize and at the same time rejuvenate the ecological nutrients. This method is also useful to achieve food production succession in the Nigerian savannah. For example, some farmers indicated that the planting of local vegetable *Corchorus* (*Ewedu*), maize, and yam together on the same plot will provide a continuous income generation. The vegetable will be harvested after 3 or 4 weeks; maize will last for 10–12 months, while yam will last for 9 months.

Rotation of crops and shifting cultivation is traditional and does not require much technicality. Crop rotation is done by alternating crops that are planted on different plots at every planting season. For example, a farmer with three plots will arrange crop planting in a way that yam, maize, and okra are interchanged on the plots at the next planting season. To do shifting cultivation, farmers abandon a plot of land after a successive planting season and shift to another plot in the following year. The "abandoned" plot is allowed to rejuvenate for a period of one or more planting season and will be occupied again. For farmers who have large hectares of land, this agricultural method might be appropriate.

Crop switch/substitution: the strategy involves planting of crop species that have short growing periods and are more tolerant to rainfall shortages. During the KIIs, the traditional ruler in Iganna indicated that water yam, which has 3 months maturity period, is usually planted instead of white yam which would last for 9 months. Yellow yam which is more tolerant to drier period is also substituted with white yam. Yellow yam is largely cultivated for yam flour production because the by-product also last longer in storage especially when the flour is produced for exportation.

Post Planting

For most women who are engaged in collection of fruits, seeds, nuts and leaves (especially herbal leaves), delineation of harvest zone are evolving in some communities. Part of the activities to address the threats to the forest as suggested by the respondents includes replanting of trees after harvesting as being practiced by 31 % of the respondents, while 56 % did not replant any trees after harvest. Meanwhile, 13 % of the respondents are unconcerned or indifferent about tree planting perhaps due to lack of awareness or local capacity. Most farmers believed that trees and other woodland resources are reproduced by nature itself. About 70 % of the people had no formal training about farming, forestry, and ecosystem management nor participate in training on any forest management program. Only 17 % indicated that they have participated in forest management training. This says a lot about the capacity of the people to manage their ecosystem and associated resources beyond their local knowledge. Majority of those who claimed they had training on forest management did not put it into practice because they could not afford the implementation cost.

Off-Farm Coping Strategies

These are activities that farmers engaged in outside farm plots in order to maintain status quo during dry season when water supply shortages hinder effective farming.

Livelihood Diversification

This is the most common option which is manifested in the following ways:

Firewood harvesting: Collection of firewood is a common diversification as a form of coping strategy and alternative income generation especially during dry season when there is shortages of water supply to support cultivation of land for planting. This activity is done in large scale around the study area. Apart from exportation of the fire wood to urban centers, domestically, about 84 % of the people depend on firewood for cooking and heating (Fig. 5). It is also the most preferred source of fuel by 59 % either because it is readily available (42 %), freely accessible (14.6 %), and affordable (13.5 %). The implication of this form of livelihood on ecosystem is destroying because of the fact that trees that are harvested for fuel wood are never replanted except the effort of natural regeneration as confirmed by 56 % of the participating farmers.

Charcoal production: As a result of land degradation and shortage of water to support farming livelihoods, another major off-farm diversification is charcoal production. The conversion of wood into charcoal is done by the majority (68 %) of the population (youth in particular) because it generates income faster than crop planting that may wait until the planting and harvesting cycle is completed. Charcoal is on high demand as a main cooking energy source for both local and export to big cities. Engagement with some charcoal producers shows that they target some species of wood, especially the *Vitellaria paradoxa*, which are believed to be excellent for charcoal making. A matured tree (about 15 m high) will produce about ten bags of charcoal. Our investigations also reveal that the farm gate price for a bag of charcoal is between N700 and N800 (about USD5). This means that a matured tree which may have been more than 25–30 years old is sold for between N7000 and N8000 (about USD50).

Youths and adult age groups who are engaged in charcoal and firewood making will be affected if tree logging and deforestation are totally banned. When the short-term gain is compared to the ecosystem services provided by the same tree and more importantly by the regulating function such as carbon sequestration, the need to plan for alternative livelihoods and trade-offs if the ecosystem must be protected and if the active population will remain in the rural communities is inevitable.

Institutional Architecture

There is virtually no institutional collaboration work to promote ecosystem management and food security around the study area except for the Fadama project. A form of partnership is working in Kwara (one of the states covered in this study) among the Zimbabwean farmers in Shonga (located in Edu LGA in the rich River Niger alluvial floodplain). The project was supported by a public-private partnership strategy in which the state government provided the finance and other infrastructure.

Protection of Watershed and Water Storage

Most farmlands have watersheds which are thriving during wet season. During dry season, some of these watersheds are demarcated purely for certain farming activities. For instance, spring waters (*Seleru*) around some rocky areas (*ada*) in some localities are purely used for food processing such as cassava flour and yam flour because such water resource is very close to where the farmers will spread their product for solar heating.

In relation to water storage, most farming households have big water pots, each having at least 200 l capacity. Water harvest is usually done during the wet season and stored in these pots. Basically, the stored water is used for domestic purposes and irrigation of vegetable gardens at the back of house in the farm (“eyin abule”) when the rainy period ceased. In achieving some results from this option, most farmers indicated that they try to reduce the volume of water for some uses. This is a form of behavioral shift. Discussion with some farmers during the fieldwork indicated that the storage capacity is not adequate to sustain farming households throughout the dry season. In recent times, some farmers are now drilling wells which can serve them for food processing and domestic needs.

Appealing to the Goddess

During the interaction with some of the community leaders in the study area, it was revealed that another indigenous way of dealing with water supply shortages especially during extreme dryness (drought or sudden cessation of rain) is to appeal to the farm goddess (*Orisa Oko*). To do this, the community leaders and the goddess priests are principally involved to make rituals. When this is adequately done, it is believed that rain will start mostly 3 days (*ita*) post the appealing.

Conclusions

This chapter has shown that water variability in the Nigerian savannah is as a result of seasonal rainfall variation. The analysis of the farmers’ perceptions of climate change and water variability indicates that most of the farmers in the study area were aware that temperature is increasing, and the level of rainfall is declining. Observed station data and community perception indicates the delay in the onset of rain, earlier cessation of rain, and reduction in the number of raining days during wet season. These anomalies had implication for food production in the region because farming activities are basically rainfed. Planting seasons are already altered, while most participating farming households and community leaders revealed that the shortage in water supply and land degradation have impacts on their farm produce.

In the midst of these challenges, on-farm and off-farm coping options which are used during preplanting, planting, and post-planting seasons are available. Generally, the coping capacity of the study communities is very weak. However, engagement with the stakeholders during the feedback workshop shows that there is a general willingness to participate in ecosystem management and adopt new farming techniques. In the light of the above, the following suggestions are recommended as viable road map to sustainable food production and rural livelihoods in the Nigerian savannah:

- Reviving the old partnership practices: people and community leaders recalled with nostalgia the late 1970s and early 1980s when agricultural extension officers were regular and farming advice and inputs were provided through agencies such the Ogun-Osun River Basin Development Authority (OORBDA) and Oyo State Agricultural Development Programme (OYSADEP). Some of these organizations used to have offices within the community, and they hold regular meeting with the communities and advise them on climate, agriculture, forestry, food production, and rural livelihoods.

- Pro-food production agenda in poverty reduction programs: improving on the implementation of the existing poverty-focused policies and programs meant to transform the currently low-productivity agricultural sector where significant proportion of the population currently makes its livelihood. It is therefore important that programs such as Fadama should be more strengthened to allow more participation of rural farmers.
- Mainstreaming climate adaptation into food security policies: food security and adaptation to climate change are mutually supportive approaches. Design of food security programs must therefore take climate variability since farming is basically rainfed. In doing this, it is important that most of the national policies relating to agriculture and water resources are integrated climate change scenarios, downscaled and implemented locally.
- Water harvest: given the amount of total annual rainfall in the region and the availability of some watersheds, it is important that mechanisms for water collection are looked into both at the household and community levels. When this is done properly, it might salvage the challenge of irrigation.
- Institutional radicalization: it is observed that there is a need to rearchitect most institutions within the water and agricultural sectors in Nigeria. Since farming is mostly done by private individuals, this reality must be built into the institutional structures.
- Climate services: the forecasting tools currently deployed are regional in approach and general in perspective. This means a densification of existing meteorological network as well as arrangement to present end users (local farmers) with seasonal forecasts in a clear and simple language. More importantly, the Agricultural Meteorology Department of NIMET must be equipped in terms of capacity development on local climate forecasts.

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Integrated Biophysical and Socioeconomic Model for Adaptation to Climate Change for Agriculture and Water in the Koshi Basin

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Contents

Abstract

Water vulnerability is one of the major challenges facing people in the Himalayan river basins and is expected to increase with climate and other change. In order to develop appropriate and effective adaptation strategies, it is necessary to understand the level and spatial distribution of water vulnerability and the underlying factors contributing to it, both biophysical and socioeconomic. The development and application of a water vulnerability assessment model at district level, and its use in adaptation planning, is described using the

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transboundary Koshi River basin as an example. The whole basin showed a relatively high degree of water vulnerability, with mountain districts the most vulnerable followed by the mid-hills and the plains. The mountain and mid-hill areas were more vulnerable in terms of resource stress and ecological security, whereas the plains areas were more vulnerable in terms of development pressure; all parts of the basin were vulnerable in terms of management capacity. Significant correlation among the four components indicated that improvements in resource availability, ecological security, and management capacity would reduce development pressure and overall vulnerability. Adaptation plans need to be based on district-specific vulnerability characteristics; some suggestions and recommendations for adaptation plans are made.

Keywords
Koshi basin • Integrated model • Climate change • Adaptation • GIS • Socioeconomics

Introduction

Water is a multidimensional resource used for industrial, domestic, agricultural, and recreational purposes. In the majority of developing countries, a significant proportion of the total water withdrawal is for agricultural purposes, and there is a very strong linkage between water availability and peoples' livelihoods, as most livelihoods depend on agriculture. Water availability is mainly influenced by climatic parameters, such as rainfall, temperature, and snowfall, and anthropogenic changes, such as changes in the human and livestock populations, economic development, and urbanization (Kundzewicz and Somlyody 1997). The anthropogenic changes can in turn affect the climatic parameters leading to further change. Many drivers of change impact on current and future water availability, and water is considered to be a vulnerable resource to different degrees globally (Rosenzweig et al. 2004; Bates et al. 2008) increasing the challenges to water resource management (Kojiri 2008). The vulnerability of water resources directly affects peoples' livelihoods leading to increased poverty and problems of food and energy insecurity (Rasul 2012, 2014). Normally, poorer people in developing countries are more, and more rapidly, affected (Sullivan and Meigh 2005) because they are less resilient and have limited options for coping.

A water vulnerability assessment is a key entry point for suggesting suitable policy options for the sustainable utilization of water resources and plans for adaptation (Kelly and Adger 2000). The concept of vulnerability is complex and context specific, and different assessment tools have been developed for different purposes at different scales. The study described here focused on developing a water-based vulnerability assessment that could be used to develop adaptation strategies based directly on the parameter and linked indirectly with water resources specific to the study area. The study used UNEP water vulnerability assessment tools

(Babel and Wahid 2009a, b; UNEP 2011) as a framework, with some modifications and additional context-specific water-related variables so that it can be replicated in transboundary river basins of the Hindu Kush Himalayas. The strength of the approach is that it treats the biophysical and socioeconomic aspects of the river basin equally, in contrast to other studies which have tended to ignore the socioeconomic component. The water issues of the Koshi basin were used as a case study for transboundary river basins of the Hindu Kush Himalayan region; districts were taken as the smallest unit to allow empirical estimates of the current vulnerability scenarios of the basin at district level, identify basin specific vulnerability factors, and suggest suitable policy options. The study contributes to the conceptualization and methodological advance of water vulnerability assessment tools and demonstrates the applicability of the model and its contribution to adaptation planning using the Koshi basin as an example.

Notable studies on water vulnerability assessment in South Asian river basins include one for the lower Brahmaputra river basin (Gain et al. 2012) and one for the Ganges-Brahmaputra-Meghna river basin (Babel and Wahid 2011), both at macrolevels. Microlevel water vulnerability assessments have been conducted for the Bagmati River basin (Babel et al. 2011; Pandey et al. 2011) and medium-sized river basins in Nepal (Pandey et al. 2010, 2012), and a water poverty analysis for the Kali Gandaki river basin (Manandhar et al. 2012). Until now, no vulnerability assessments have been carried out at a transnational scale using district-level data (third-level administrative unit) to bridge the scales. The Koshi River is one of the major tributaries of the Ganges, and the river basin is characterized by a high level of poverty and food insecurity and thus offers a useful example for developing and testing the assessment approach.

The development of the water vulnerability assessment model, and application in planning for adaptation to climate change, is described in the following: the framework is presented in the first section; the second section describes the application of the model in a vulnerability assessment of a transboundary river basin at district level and its use in adaptation planning using the Koshi River basin as an example; and finally the approach and results are discussed and conclusions drawn.

Framework for a Vulnerability Assessment

Vulnerability is a complex concept; it differs from one discipline to another and is highly context specific (Young et al. 2010). The most widely used definition of vulnerability is that given by the IPCC (Intergovernmental Panel on Climate Change): “Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes” (McCarthy et al. 2001). Vulnerability (V) can be expressed as

$$\mathrm{V} = \mathrm{f}\ (\text{exposure}, \text{sensitivity}, \text{adaptive capacity})$$

The exposure and sensitivity of a system are related to hazards and cause the vulnerability, while the adaptive capacity is a “shock absorber” and has an inverse relationship to exposure and sensitivity (Brooks et al. 2005; Hamouda et al. 2009). Biophysical forces are responsible for the exposure and sensitivity of the system, while sociocultural, political, and economic forces contribute to the adaptive capacity (Adger 2006; Smit and Wandel 2006).

Why Use an Integrated Modeling Approach for Water Vulnerability Assessment?

Most vulnerability assessments have been based on physical or biological disciplines (Sullivan and Meigh 2005) which view vulnerability in terms of the likelihood of occurrence of climate-related events (Adger 2006). This conventional approach is a top-down or end-point approach and does not look at adaptation options to cope with the vulnerability (Young et al. 2010). In contrast, social scientists view vulnerability as a set of socioeconomic and institutional factors that determine people’s ability to cope with stress or change (Kelly and Adger 2000; Brooks 2003). According to Sen, socioeconomic parameters such as access to essential resources like forest, land, and water should also be reflected in the vulnerability analysis (Sen 1981, 1990). Similarly, Adger et al. (2005) strongly emphasized the importance of incorporating socioeconomic systems with biophysical systems at varied spatial and social scales in the vulnerability assessment. O’ Brien et al. defined vulnerability to climate change as a function of a range of biophysical and socioeconomic factors (O’ Brien et al. 2004). Incorporating socioeconomic parameters into a vulnerability assessment is called a bottom-up or starting-point approach and has direct application in adaptation planning (Young et al. 2010). In the past, the vulnerability created by socioeconomic factors was largely ignored (Adger and Kelly 1999), in part because of the quantification and indexing problems for qualitative and quantitative data (Cutter et al. 2003; Plummer et al. 2012).

Water-based vulnerability assessments should also incorporate socioeconomic factors (Sullivan 2011) because people constantly interact with water resources for their livelihoods, and social factors make a significant contribution to water vulnerability (Sullivan and Meigh 2005). Incorporating socioeconomic factors in water vulnerability assessments will enable more effective adaptation strategies to be developed (Vorosmarty et al. 2000; Sullivan and Meigh 2005) and provide a holistic approach along the lines of integrated water resources management (IWRM) (Vorosmarty et al. 2000; Babel and Wahid 2011; Plummer et al. 2012).

Two of the earliest studies using biophysical and socioeconomic parameters in water vulnerability assessments are those by Boruff et al. (2005), who combined physical and socioeconomic factors in a model used to determine county-level vulnerability caused by coastal erosion in the USA, and by Sullivan and Meigh

(2005), who developed a climate vulnerability index (CVI) focused on water-related variables which considered a wide range of socioeconomic and physical parameters at different spatial scales. In the UNEP methodologies guideline for vulnerability assessment of freshwater resources (Huang and Cai 2009), water resource vulnerability is decomposed into resources stress (RS), development pressure (DP), ecological security (ES), and management challenges (MC). The first three are linked to the parameters of exposure and sensitivity in the conventional definition of vulnerability, while the last is linked to adaptive capacity. Sullivan (2011) considered the resource stress component to be the supply-driven aspect of water vulnerability, and the other three components to be the demand-driven aspect of water vulnerability.

Steps in Vulnerability Assessment

Figure 1 shows a schematic outline of the water vulnerability assessment framework (modified from Hamouda et al. 2009; Gain et al. 2012).

The first step is to define the water resource system that defines the biophysical and socioeconomic components. The second step is to define the problems in the system and choose the scale. Major water-related problems include the degree of water scarcity for different sectors, water pollution, erosion, upstream deforestation, land degradation, upstream and downstream conflicts, food insecurity, and incidence of poverty. Spatial scales can range from the whole basin or sub-basin to watershed, community, or individual levels; temporal scales decide whether the study is a monthly, seasonal, annual, or long-term assessment. The selection of spatial and temporal scales depends on the nature and scope of the work.

The third step is to select an appropriate analytical tool or model. There are more than 50 models available for water vulnerability analysis (Plummer et al. 2012). The most suitable model for the study should be selected and modified based on the nature of the problem to be addressed. The next step – identifying and defining the indicators of vulnerability – is a very important part of the analysis. Vulnerability is a complex concept and cannot be measured directly. It has to be represented using a combination of proxy indicators and variables, even though this does not represent it fully (Brenkert and Malone 2005). Sullivan and Meigh (2005) defined an indicator as a statistical concept that provides an indirect way of measuring a given quantity and state and allows for current assessment and comparison over time. According to Vorosmarty et al. (2000), the indicators should be relevant to the issues, policy relevant, analytically and statistically sound, understandable, and easy to interpret. There are two approaches to indicator selection: firstly, from the literature, using inductive or deductive approaches, and secondly, from expert judgment (Hinkel 2011).

After the list of indicators and subindicators has been developed, the data collection can proceed. Stakeholder's participation and field visits are important for triangulation.

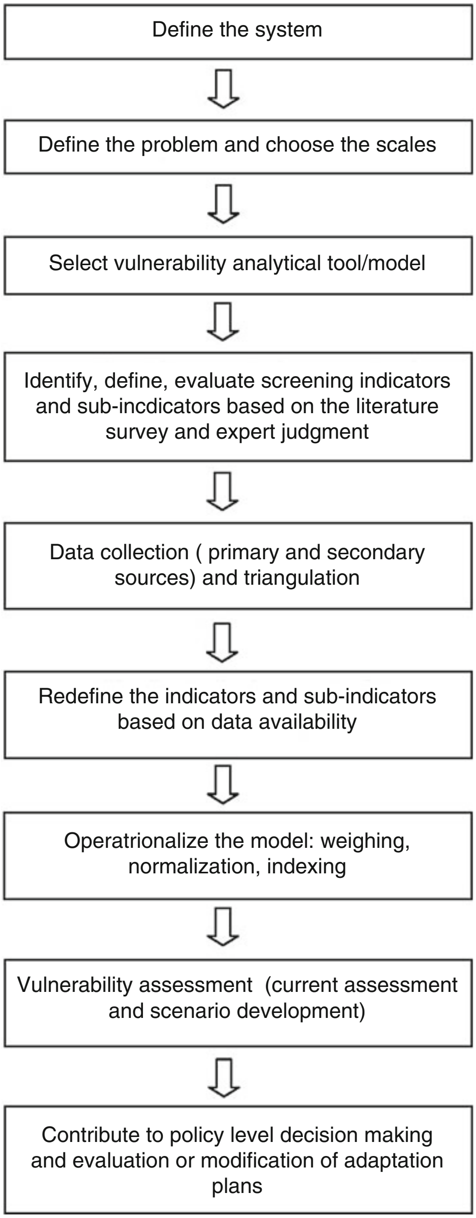


Fig. 1 Framework for water vulnerability assessment

After the data has been compiled, the indicators should be redefined based on the data availability. The indicators are then normalized and entered into the vulnerability model. Finally, the model is run, the results are interpreted, and policy recommendations are made.

Application of the Vulnerability Framework to the Koshi River Basin

The water vulnerability assessment framework (Fig. 1) was applied to the Koshi River basin at district scale. The aim was to identify the vulnerable districts and the biophysical and socioeconomic factors contributing to basin vulnerability and to use this to recommend location-specific adaptation strategies that can help policy makers to evaluate or modify existing policy options for adaptation management strategies for water resources (Babel et al. 2011). The individual steps in the assessment are described in the following.

Defining the Koshi System and the Problem

The Koshi River basin is a transboundary basin which originates in the southern area of the Tibetan Plateau in China, passes through Nepal from north to south, and then crosses the northern part of Bihar in India before joining the Ganges. The basin can be broadly divided into four geographical regions (Fig. 2): the Transhimalayan region, which consists of six counties in Tibet Autonomous Region of China (>3,500 masl); the mountains, comprising five mountain districts in eastern Nepal (3,500–8,000 masl); the mid-hills, comprising 11 mid-hill districts in Nepal (1,000–3,500 masl); and the Terai (plains area), comprising 11 Terai districts in Nepal and 16 districts in Bihar state in India (<1,000 masl). For the purposes of the study, the first three were taken as the upstream and the Terai districts as the downstream.

The Koshi is a major tributary of the Ganges and the third largest river in the Himalayas after the Brahmaputra and Indus (Sharma et al. 2000). The river basin covers an area of 90,404 km^2, 22 % in India, 33 % in China, and 45 % in Nepal. It is home to more than 50 million people, most with livelihoods based on agriculture. Both the socioeconomic and the biophysical gradients of the basin change with elevation, resulting in differences in water availability and accessibility in different parts of the basin and thus differences in water vulnerability. The upper part of the basin has problems associated with snowmelt, water runoff, soil erosion, and land degradation, while the lower part has problems associated with waterlogging, population growth, expansion of agricultural land, and urbanization.

Rainfall in the basin is highly variable in time and space. The annual rainfall ranges from 207 mm in the Transhimalaya to more than 3,000 mm in the eastern mountains and mid-hills of Nepal (Fig. 3). More than 80 % of the rainfall is from the downstream monsoon, which occurs from July to September. Climate change is expected to increase water scarcity, and this together with socioeconomic changes is expected to decrease the per capita water availability for domestic and agricultural use, which will ultimately influence the agro-based livelihoods of the people in the basin and threaten food security. The per capita water availability per annum in the countries that share the basin (2,060, 1,784, and 6,895 m^3 per

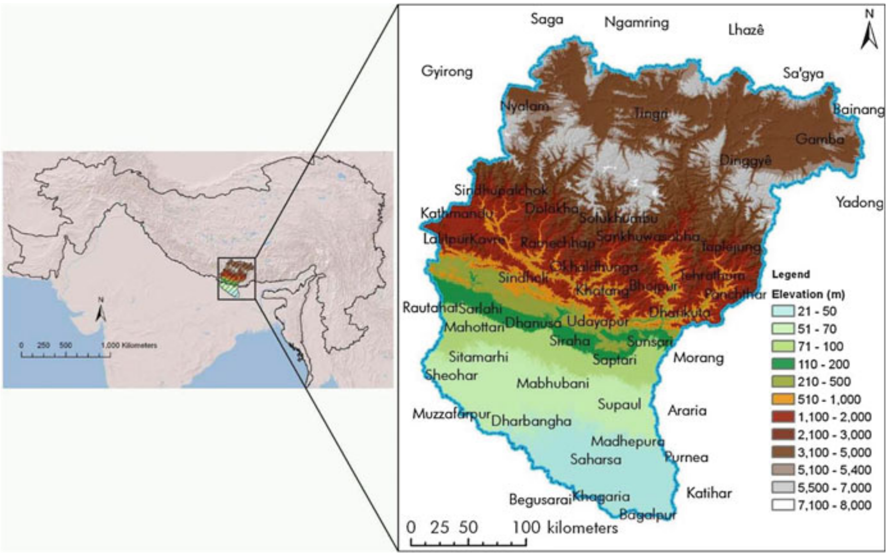


Fig. 2 The Koshi basin study area

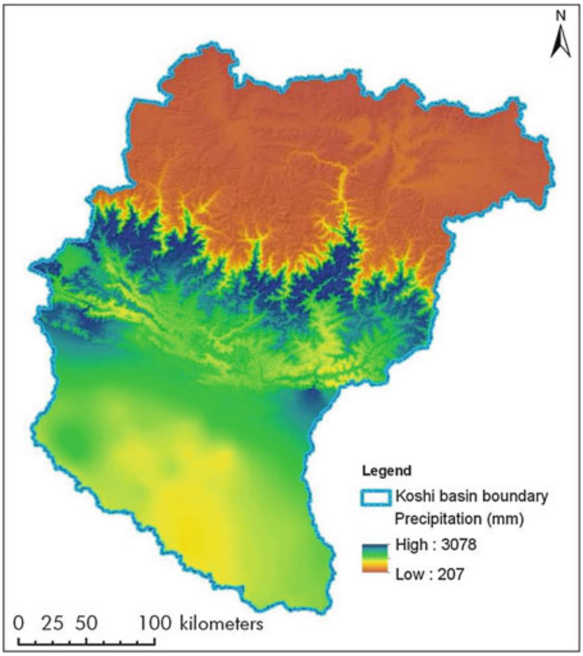


Fig. 3 Average annual rainfall in the Koshi basin

capita for China, India, and Nepal, respectively) is higher than the water poverty threshold of 1,700 m^3 (Falkenmark and Widstrand 1992) but lower than the world average of 7,243 m^3; and actual water withdrawal is considerably lower than the availability (584, 805, and 966 m^3 per capita per annum for China, India, and Nepal, respectively) (Rosegrant et al. 2002; Babel and Wahid 2011; FAO AQUASTAT 2013).

Selection of the Vulnerability Assessment Model

The UNEP water vulnerability assessment model (Babel and Wahid 2009a, b; UNEP 2011) was selected for the Koshi basin assessment. The advantages of this method are first that it offers a flexible and holistic approach that combines biophysical and socioeconomic indicators and second that it has been widely used for determining water vulnerability at basin level and is simple to calculate and the results easy to interpret. In this model, vulnerability is decomposed into resource stress (RS), development pressure (DP), ecological security (ES), and management challenges (MC). Resource stress is defined as the pressure on the water resources resulting from socioeconomic and environmental change (Babel et al. 2011); development pressure refers to the main socioeconomic development activities in the basin; ecological security refers to the ecological health of the basin, because the quality of the environment is an essential factor for sustainable use of water resources and coping with water stress (Manandhar et al. 2012); and management capacity (also called social vulnerability) refers to people's ability to manage water and is directly linked with the adaptive capacity of the basin. Mathematically, water vulnerability can be expressed as water vulnerability = f [resource stress (RS), development pressure (DP), ecological security (ES), management challenges (MC)].

The vulnerability index (*VI*) is calculated by aggregating and assigning weights to the four vulnerability components. The water vulnerability equation can be presented as

$$VI = \left[\sum\nolimits_{i=1}^{n}\left(\sum\nolimits_{j=1}^{m_i} X_{ij} \times w_{ij}\right) \times W_{ij}\right] \tag{1}$$

where

VI is the vulnerability index

n is the number of vulnerability components

m_i is the number of parameters in the ith component

X_{ij} is the jth parameter in the ith component

w_{ij} is the weight to the jth parameter in the ith component

W_{ij} is the weight given to the ith component

VI has a value between 0 and 1, with higher values representing higher vulnerability.

Preliminary and Final Identification of Indicators, Subindicators, and Variables

A list of potential socioeconomic and biophysical variables closely linked with water vulnerability was prepared using an intensive literature survey and intuitive understanding of society-water interactions (Sullivan 2002; Lawrence et al. 2002; Brooks et al. 2005; Pandey et al. 2012). Expert opinion was also solicited from an interdisciplinary team. The variables were then grouped broadly under the four components of water vulnerability proposed by UNEP. In all 88 biophysical and socioeconomic variables were identified as potential variables in the preliminary list, 19 related to resource stress, 24 to development pressure, 16 to ecological security, and 29 to management capacity.

After listing potential indicators and variables, data were collected from secondary sources including the Central Bureau of Statistics (2001, 2003, 2004, 2011), Census of India (2001, 2011), Central Bureau of Statistics and International Centre for Integrated Mountain Development (2003), Central Bureau of Statistics, World Food Programme, and World Bank (2006), Chaudhuri and Gupta (2009), Nepal Living Standards Survey (NLSS 2011), and Ministry of Agricultural Development/Government of Nepal (2012). Where possible, long-term data were collected for the individual variables; where these were unavailable, multiple year data were collected, or data from a single year was used as a proxy for long-term data as suggested by Brooks et al. (2005). The list of potential indicators and variables was then evaluated. Some variables were removed, either because a high level of colinearity was identified between two variables within the same component or because the data could not be accessed through secondary sources for all the basin districts. For example, the number of households that belong to an irrigation management group, an important indicator of management capacity, was available for Nepal but not for India. The final list contained 34 variables, five for resource stress, six for development pressure, seven for ecological security, and 16 for management challenges. Table 1 shows the list of variables and their functional relationship with vulnerability.

Operationalizing the Model

This integrated approach to vulnerability assessment uses a wide range of biophysical and socioeconomic variables at different scales and with different units. The indicators were normalized to a value between 0 and 1 using UNDP's normalization approach, as used, for example, in calculating the Human Development Index (HDI) (UNDP 2006). The functional relationship was taken into account while normalizing. The equations used are shown below, Eq. 2 was used for positive functional relationships and Eq. 3 for inverse relationships (modified from Turvey 2007; Hamouda et al. 2009; Islam et al. 2013):

Table 1 Indicators and variables used in the vulnerability assessment of the Koshi River basin and their functional relationship with vulnerability

Variable (year)	Unit	Functional relationship
Resource stress		
Rainfall variability (1950–2000)	Coefficient of variation	Increase
Temperature variability (1950–2000)	Coefficient of variation	Increase
Water availability	km^3	Decrease
Water withdrawal	km^3	Increase
Distance to water source	km	Increase
Development pressure		
Population density	$Persons/km^2$	Increase
Population growth	%	Increase
Arable land	%	Increase
Irrigated area	%	Increase
Livestock density/ha	Livestock units/ha	Increase
GDP per capita	USD	Increase
Ecological security		
Fertilizer use	%	Increase
Crop intensity	%	Increase
Households that use conventional energy for cooking	%	Increase
Households that use conventional energy for lighting	%	Increase
Forest area	%	Decrease
Slope	%	Increase
Erosion	%	Increase
Management capacity		
Literacy rate	%	Decrease
Permanent house	%	Decrease
Family size	Number/hh	Increase
Farm size	ha/hh	Decrease
Herd size	Number/hh	Decrease
Economically active population	% (15–59 years)	Decrease
Yield of food grain (rice yield as a proxy)	kg/ha	Decrease
Milk production	Metric t	Decrease
Irrigation coverage	%	Decrease
Drinking water coverage	%	Decrease
Sanitation (toilet facilities)	%	Decrease
Access to electricity	%	Decrease
Access to bank	%	Decrease
Households with TV	%	Decrease
Access to forest	%	Decrease
Poverty incidence	%	Increase

Table 2 Reference sheet for interpretation of the vulnerability index

Vulnerability index	Interpretation
Low (<0.2)	Healthy basin
Moderate (0.2–0.4)	Basin generally in good condition but facing issues in management capacity, needs strong policy intervention to improve the situation
Relatively high (0.4–0.5)	High stresses in the basin, needs long-term river basin plan to improve the situation
High (0.5–0.6)	
Very high (0.6–0.7)	
Severe (0.7–1.0)	Highly degraded basin, needs long-term integrated plan to improve the situation

Modified from Huang and Cai (2009)

$$X_{ij(\text{normalized})} = \left[\frac{X_{ij} - \min\left(X_{ij}\right)}{\max\left(X_{ij}\right) - \min\left(X_{ij}\right)}\right] \tag{2}$$

$$X_{ij(\text{normalized})} = \left[\frac{\max X_{ij} - X_{ij}}{\max\left(X_{ij}\right) - \min\left(X_{ij}\right)}\right] \tag{3}$$

where

Index $X_{ij\ (\text{normalized})}$ is the normalized value of an indicator

X_{ij} is the actual value of the indicator

$\max(X_{ij})$ and $\min(X_{ij})$ are the maximum and minimum values of the indicator, respectively

After normalization, the normalized values were entered into Eq. 1 to determine the vulnerability index per component and overall. According to UNEP (2011), assigning relative weights to individual indicators can be biased and will lead to problems with comparisons; thus, parameters should be assigned equal weights. For this reason, a balanced weighted average approach was used (Schulze 2007; Pandey et al. 2012; Manandhar et al. 2012) in which each of the four components contributed equally to the total vulnerability. The resulting composite score described the water vulnerability of the Koshi basin. The UNEP reference sheet shown in Table 2 was used to interpret the results.

Results

The results of the water vulnerability assessment were limited to the part of the basin in India and Nepal; this consists of 43 districts and three broad geographical zones.

Basin-Scale Vulnerability

The overall vulnerability index for the whole Koshi basin was 0.401, with a range of 0.327–0.482, which indicates a relatively high level of water vulnerability in the basin (Table 3). Of the basin districts analyzed, 51 % were moderately vulnerable and 49 % highly vulnerable (Table 4). None of the basin districts was either healthy or highly degraded. The low SD value indicates that there is little variation in the degree of vulnerability within the basin, but the sources of variation within the basin may differ.

The whole basin is moderately vulnerable in terms of resource stress and development pressure (0.35 and 0.30), but the relatively higher standard deviations of these components indicate that the degree of vulnerability varies significantly within the basin (Table 3). In both cases, more than 70 % of the districts were moderately vulnerable and only a few highly or severely vulnerable (Table 4). The index values for ecological security and management capacity for the whole basin were higher (0.46 and 0.48) and with a relatively small SD, showing a higher degree of vulnerability with smaller variation within the basin (Table 3); more than 80 % of districts were highly vulnerable in terms of ecological security and management capacity (Table 4).

Mapping Vulnerability Across Geographical and District Scales

Table 5 shows the 12 most vulnerable and 12 least vulnerable districts based on the aggregate vulnerability index. Comparison of the most and least vulnerable districts within a basin can help in designing policy options for the improvement of problematic districts by learning from less vulnerable districts. Figure 4 shows the geographical distribution of different levels of aggregate vulnerability. Overall, vulnerability tends to be higher in the mountains and mid-hills and moderate in the plains areas, with some exceptions. All five mountain districts were in the top 12 vulnerable districts (Table 5), as were 4 of 11 mid-hill districts, but only 3 of 27 plains districts. Nine plains districts and 3 mid-hill districts were among the 12 least vulnerable districts.

The aggregate vulnerability score provides a general indication of water vulnerability but does not explain the underlying causes. The component-wise values provide more indication of the causes and thus of areas of focus in developing relevant adaptation policies and strategies. Figure 5 shows the component-wise vulnerability of the Koshi basin districts from upstream to downstream; Table 6 shows the 12 most vulnerable districts for each component; and Figs. 6, 7, 8, and 9 show the geographical distribution of levels of vulnerability for the individual components.

Resource stress was generally higher in the mountains and some of the mid-hills and much lower in the plains districts (Figs. 5 and 6). The 12 most vulnerable districts in terms of resource stress included all five mountain districts, two districts from the mid-hills, and five in the plains (Table 6).

Development pressure vulnerability was generally higher in the mid-hills and plains areas (Figs. 5 and 7). The 12 most vulnerable districts included three

Table 3 Vulnerability of the Koshi basin

Vulnerability component	Minimum	Maximum	Mean	[a]SD
Resource stress	0.220	0.731	0.350	0.110
Development pressure	0.164	0.709	0.300	0.101
Ecological security	0.335	0.594	0.460	0.060
Management capacity	0.305	0.632	0.485	0.071
Overall index	**0.327**	**0.482**	**0.401**	**0.036**

[a]SD standard deviation of the mean

Table 4 No. of basin districts in different vulnerability categories

Vulnerability category	No. of districts (n = 43)				
	Resource stress	Development pressure	Ecological security	Management capacity	Overall index
Low	0	8(19 %)	0	0	0
Moderate	37(86 %)	31(72 %)	7(16 %)	5(12 %)	22 (51 %)
High	5(12 %)	3(7 %)	36(84 %)	38(88 %)	21 (49 %)
Severe	1(2 %)	1(2 %)	0	0	0

Table 5 Twelve most vulnerable and least vulnerable districts in the Koshi basin

Most vulnerable districts	Geographical area	Index	Least vulnerable districts	Geographical area	Index
Taplejung	M	0.482	Sunsari	T(N)	0.327
Solukhumbu	M	0.474	Dhanusa	T(N)	0.332
Sankhuwasabha	M	0.467	Lalitpur	MH	0.343
Ramechhap	MH	0.456	Siraha	T(N)	0.346
Araria	T(B)	0.449	Sarlahi	T(N)	0.355
Purnea	T(B)	0.446	Sheohar	T(B)	0.365
Katihar	T(B)	0.439	Saptari	T(N)	0.366
Sindhuli	MH	0.432	Bhaktapur	MH	0.367
Panchthar	MH	0.432	Mahottari	T(N)	0.369
Dolakha	M	0.427	Makwanpur	MH	0.370
Sindhupalchowk	M	0.422	Bhagalpur	T(B)	0.375
Bhojpur	MH	0.419	Morang	T(N)	0.376

M mountains, *MH* mid-hills, *T(B)* Terai (Bihar), *T(N)* Terai (Nepal)

from the mid-hills (Kathmandu, Bhaktapur, and Lalitpur) and nine from the densely populated plains area in India (Table 6).

Ecological vulnerability extended over the whole basin, but was more pronounced in the hills and mountains than in the plains (Figs. 5 and 8). All 12 of the most vulnerable districts from an ecological perspective were from mountain and mid-hill areas, and all had a relatively high index value (>0.5) (Table 6).

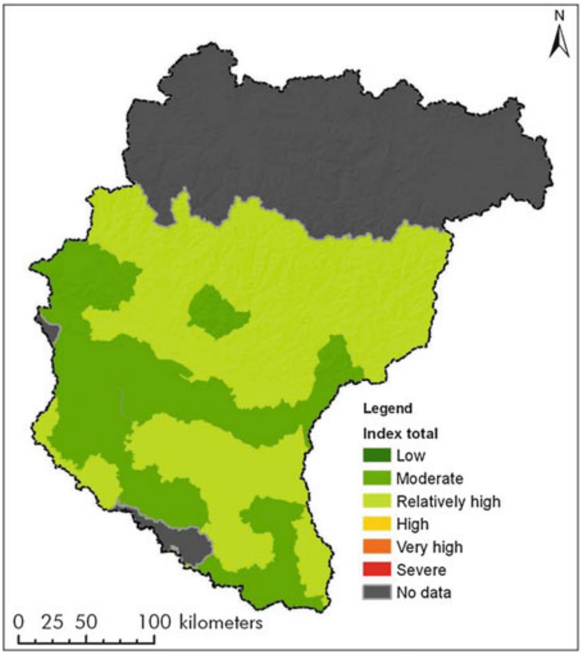
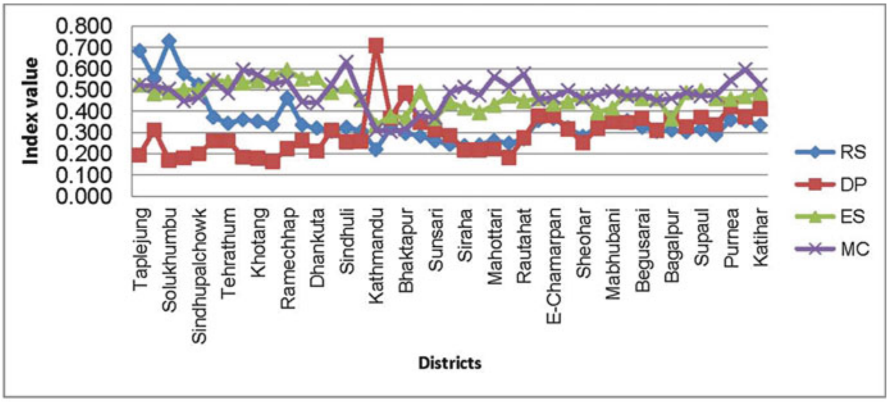


Fig. 4 Aggregate vulnerability at district level in the Koshi basin



RS= Resource stress, DP = Developmental pressure, ES = Ecological security and MC = Management capacity

Fig. 5 Component-wise vulnerability of districts in the Koshi basin from upstream to downstream

Vulnerability due to low management capacity was high in most of the basin (Figs. 5 and 9), and the 12 most vulnerable districts included districts in all three geographical regions.

Five districts (Taplejung, Ramechhap, Panchthar, Bhojpur, and Purnea) were among the 12 most vulnerable districts for three of the four components (Table 6).

Table 6 Twelve most vulnerable districts for each vulnerability component

District	Geographical area	Value	District	Geographical area	Value
Resource stress			**Development pressure**		
Solukhumbu	M	0.731	Kathmandu	MH	0.709
Taplejung	M	0.684	Bhaktapur	MH	0.486
Dolakha	M	0.577	Purnea	T(B)	0.423
Sankhuwasabha	M	0.556	Katihar	T(B)	0.412
Sindhupalchowk	M	0.524	East Champaran	T(B)	0.380
Ramechhap	MH	0.462	Muzaffarpur	T(B)	0.378
Panchthar	MH	0.372	Araria	T(B)	0.373
East Champaran	T(B)	0.366	Supaul	T(B)	0.372
Madhubani	T(B)	0.362	Lalitpur	MH	0.368
Bhojpur	MH	0.361	Begusarai	T(B)	0.367
Purnea	T(B)	0.360	Bhagalpur	T(B)	0.362
Muzaffarpur	T(B)	0.358	Madhubani	T(B)	0.350
Ecological security			**Management capacity**		
Ramechhap	MH	0.594	Sindhuli	MH	0.632
Okhaldhunga	MH	0.567	Araria	T(N)	0.597
Dhankuta	MH	0.557	Bhojpur	MH	0.595
Kavre	MH	0.550	Rautahat	T(N)	0.576
Panchthar	MH	0.547	Khotang	MH	0.570
Khotang	MH	0.542	Mahottari	T(N)	0.562
Tehrathum	MH	0.538	Panchthar	MH	0.546
Bhojpur	MH	0.534	Purnea	T(I)	0.545
Taplejung	M	0.523	Ramechhap	MH	0.544
Sindhuli	MH	0.516	Okhaldhunga	MH	0.527
Dolakha	M	0.502	Udaipur	MH	0.527
Sindhupalchowk	M	0.501	Taplejung	M	0.524

M mountains, *MH* mid-hills, *T(B)* Terai (Bihar), *T(N)* Terai (Nepal)

The Relationship Among the Vulnerability Components

The results of correlation analysis among the four components of water vulnerability are shown in Table 7. Resource stress, ecological security, and management capacity have a positive and linear relationship with each other and a negative relationship with development pressure. In other words, improvement in any of the first three components will improve the others and reduce development pressure and the overall vulnerability index; conversely, any deterioration in these components will generate adverse effects.

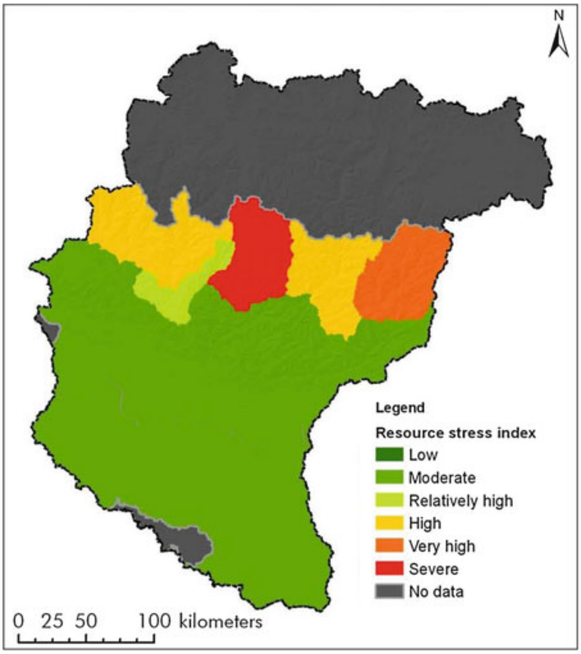


Fig. 6 Resource stress vulnerability at district level in the Koshi basin

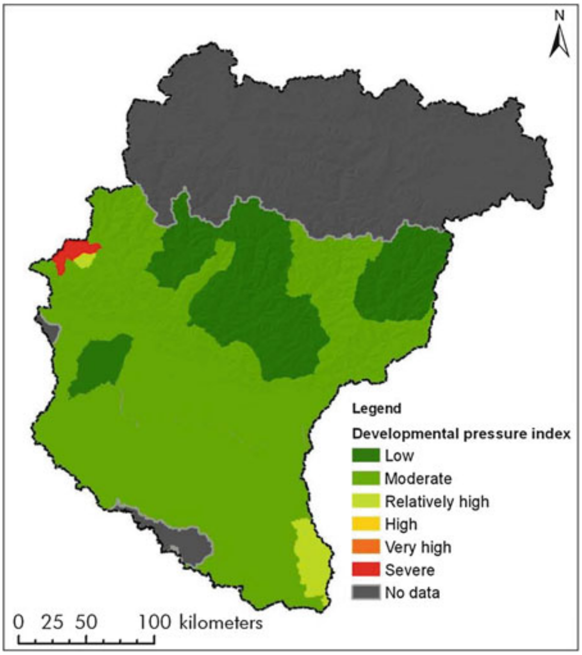
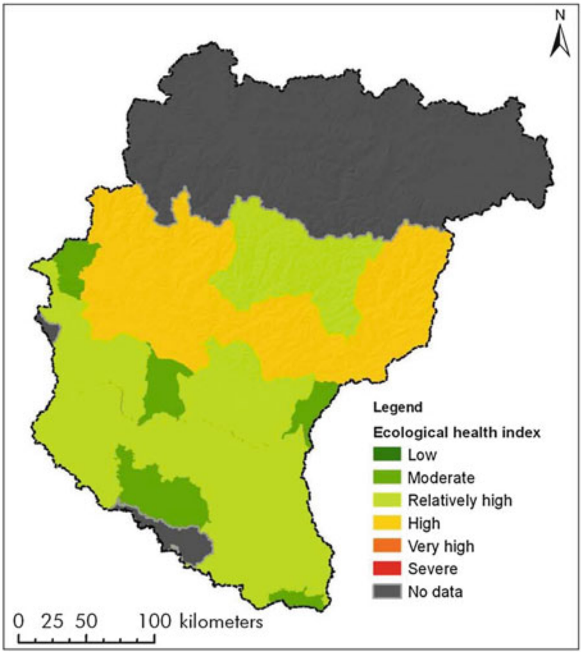


Fig. 7 Development pressure vulnerability at district level in the Koshi basin

Fig. 8 Ecological vulnerability at district level in the Koshi basin



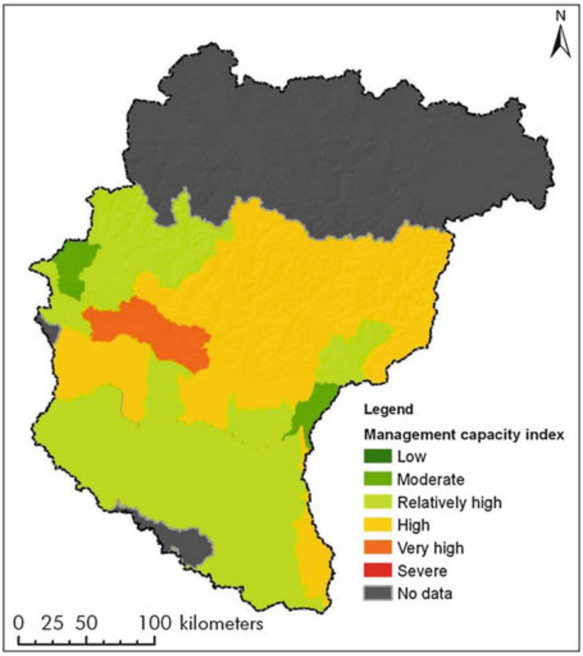


Fig. 9 Management capacity vulnerability at district level in the Koshi basin

Table 7 Correlation analysis among the components

Component	Resource availability	Development pressure	Ecological security	Management capacity
Resource availability	X	Significant (at 5 %) and negative relationship	Significant (at 1 %) and positive relationship	Not significant but coefficient is positive
Development pressure		X	Significant (at 1 %) and negative relationship	Significant (at 1 %) and negative relationship
Ecological security			X	Significant (at 1 %) and positive relationship
Management capacity				X

Discussion

There was a higher incidence of overall vulnerability in the mountain and mid-hill areas. This can be linked to the mountain specificities (Jodha 1990; Rasul and Karki 2007) and the policy bias affecting mountain areas (Rasul and Karki 2007). The variation in vulnerability among districts within each geographical region is a result of the district-specific socioeconomic and biophysical characteristics, which can be looked at using the component-wise vulnerability results and their interrelationships.

Resource stress was not a major issue in most of the districts in the plains; water in this area is generally abundant and underutilized (Shah et al. 2006). However, it was critical in the mountain districts and some mid-hills districts, such as Bhojpur and Dhankuta, where most people have to rely on rainfall as their main or only source of water. The high resource stress in these areas may be related to the problems of higher slope gradient, high runoff, and greater variability in rainfall (ICIMOD 2009). Resource stress is expected to intensify with climate change. Resource stress was negligible in the plains area of Nepal and most of Bihar. Many reports suggest that the major problems in Bihar relate to waterlogging and flooding rather than water stress (Government of Bihar 2012). The somewhat higher incidence of resource vulnerability in some Bihar districts (Table 6) is mainly due to lower and variable rainfall, drought is prominent in these districts (Government of Bihar 2012).

In contrast to resource stress, development pressure had a higher incidence in the plains areas as well as in a few urban hubs in the mid-hills. This results from higher population growth and more economic activities in comparison to the mountains and most of the mid-hills.

Ecological vulnerability was higher in the mountains and mid-hills as a result of higher rates of deforestation, higher livestock pressure, and slope farming, consistent with the findings of Jodha (1990). Babel and Wahid (2011) also observed more ecological problems in the (higher) Nepal part of the Ganges-Brahmaputra-Meghna basin than in the (lower) Indian part. However, the ecological problems upstream have a negative impact downstream. The lower ecological vulnerability in a few mid-hills districts may be due to the recent increase in community forestry in those areas in comparison with other parts of the Koshi basin (Sharma et al. 2000). The higher vulnerability in a few districts in the plains area might be due to relatively higher fertilizer use, lower forest coverage, and more use of conventional sources of energy.

Vulnerability due to a lack of management capacity was widespread in the basin irrespective of geographical zone and was particularly high in districts with higher poverty and illiteracy rates and poor performance of other socioeconomic variables. Here the problem is not so much lack of the resource but more lack of capacity to manage what is available. The low index values in the three mid-hill districts of Kathmandu, Lalitpur, and Bhaktapur (which together form Kathmandu Metropolitan City) are due to the higher socioeconomic indicators in those districts and are consistent with the findings of Pandey et al. (2012) on the Bagmati River basin.

Five districts – Taplejung (mountains), Ramechhap, Panchthar, and Bhojpur (mid-hills), and Purnea (plains) – were among the 12 most vulnerable districts for three of the four vulnerability components and can thus be considered as hot spots of vulnerability. The nature of vulnerability in these districts is more multidimensional and widespread than elsewhere and thus requires immediate intervention for recovery.

The strong positive relationship between resource availability and ecological security indicates that an increase in resource availability will also increase the ecological security, for example, an increase in moisture in the Koshi basin will result in an increase in biomass. Equally, improving the ecological security will enhance resource availability, for example, by improving the water retention capacity of the watershed. The reverse is also true, a decrease in resource availability will reduce ecological security and vice versa. The positive, but not significant, relationship between resource availability and management capacity indicates that improved management capacity cannot significantly increase the resource availability, this may be the result of the high levels of poverty. Unlike other basins, the Koshi has abundant water but people cannot use it due to the lack of economic investment.

The strong negative correlation between development pressure and ecological security indicates that an increase in development pressure will lead to a decrease in ecological security. For example, an increase in agricultural land will decrease forest cover, and cultivation of cereals on sloping land will increase soil erosion. The strong negative correlation between development pressure and management capacity indicates that increasing the management capacity will decrease the development pressure. For example, if people's management capacity is strengthened, they will switch to more efficient methods of farming, use water in more profitable sectors, and use more efficient methods of irrigation, all of which decrease the development pressure.

Finally, the strong positive relationship between ecological security and management capacity indicates that when people's management capacity is strengthened, they will switch to more ecologically appropriate practices, for example, agroforestry in place of cereal cultivation, which will increase ecological security by reducing erosion and land degradation.

The extent and causes of vulnerability within the Koshi basin differ from one geographical zone to another and from one district to another. Some districts are stronger in one aspect and weaker in others. Therefore, any adaptation plan must be based on the district-specific vulnerability characteristics and the relationship among the vulnerability components.

Conclusions and Policy Implications

The results describe the development of a water vulnerability assessment tool based on a modification of the UNEP model and its use to assess water vulnerability in the Koshi basin at district level. The overall vulnerability of the Koshi basin was relatively high, with mountain districts the most vulnerable followed by the mid-hills and the plains. The 43 districts were mapped using a biophysical and socioeconomic modeling approach based on four components of vulnerability, and the results converted into GIS interfaces. The component-wise vulnerability assessment showed that mountain and mid-hill areas (upstream) are more vulnerable in terms of resource stress and ecological security, whereas the plains areas are more vulnerable in terms of development pressure, while all parts of the basin were vulnerable in terms of management capacity. Five districts were identified as hot spots of water vulnerability that need immediate attention to improve the situation.

Significant correlation among the four components indicated that improvements in resource availability, ecological security, and management capacity would reduce development pressure and overall vulnerability, while deterioration in any of the three components would have the reverse effect.

The validity of the model could be increased in further studies by adding important parameters like water quality and using field surveys to obtain data. Assessment of smaller areas, for example, at VDC or ward level, would also improve the assessment of vulnerability.

This study shows clearly that adaptation plans should be based on location-specific vulnerability characteristics rather than using a blanket approach. The findings will help policy makers to identify the water vulnerable geographical zones and districts and to frame policy plans for these particular locations.

Recommended adaptation options to reduce the resource stress upstream include construction of storage structures like rainwater storage tanks and reservoirs and rehabilitation of old infrastructure (ICIMOD 2009; Bartlett et al. 2010). These measures would also help provide a continuous water supply to the downstream during the dry season.

Recommended adaptation strategies to reduce development pressure without compromising the net social benefit include incorporating improved crop varieties and reducing cropping intensity; introducing water demand management strategies such as increasing water productivity and water use efficiency by diverting water to more profitable crops, and using more efficient irrigation methods; and replacing low yielding cattle with higher yielding cattle.

Recommended adaptation strategies to reduce ecological vulnerability include afforestation of barren land, replacement of cereal crops on sloping land by agroforestry practices and hedgerows (White and Bhuchar 2006), increasing access to electricity in the basin from the present low rates to help lower the deforestation rate, and using balanced amounts of fertilizer (downstream) and/or green manure to maintain soil fertility. Introduction of adaptation strategies upstream will also help improve ecological vulnerability downstream.

Finally, it is essential to increase management capacity, which is mostly governed by socioeconomic factors, across the basin. Management capacity should be improved through government capacity building programs in such areas as food security, literacy, and rural electrification.

The significant interrelationships among the vulnerability components suggest that adaptation plans designed to improve one component will automatically result in improvements in the other components. Similarly, the Koshi basin has strong upstream downstream linkages. If suitable adaptation plans are adopted upstream, this will bring positive benefits downstream, while maladaptations upstream will have a negative effect downstream. This study recommends the need for a mountain-specific policy focus as suggested in Rasul and Karki (2007).

Finally, the study recommends carrying out a comprehensive vulnerability assessment at community or household level using field data in order to clearly identify the vulnerable sections of society, since it is people, not administrative units, who are vulnerable (Brooks et al. 2005). This study acts as an entry point for such studies by identifying the vulnerable locations within the Koshi basin.

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Nationally Appropriate Mitigation Actions for the Dairy Sector in Malawi: Needs and Opportunities

Irina Arakelyan and Dominic Moran

Contents

Abstract

Developing country agriculture makes a significant contribution to climate change, and the sector offers considerable potential for exploring synergies and trade-offs between mitigation, food security, and poverty reduction. But few developing countries will adopt unfunded measures to reduce greenhouse gas emissions if they compromise development and growth. Nationally appropriate mitigation actions (NAMAs) have been mooted as a means to develop possible funding modalities either within the United Nations Framework Convention for Climate Change (UNFCCC), from aid donors, or other parties seeking to fund emissions offsets in low-income countries. This chapter explores the identification of climate-smart practices that might be included under the

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definition of agricultural NAMAs. It outlines elements relevant to the development of triple-win agricultural NAMAs in the smallholder dairy sector in Malawi and offers survey evidence identifying pro-poor mitigation practices, technologies, and policies for the dairy sector by assessing the current baseline and analyzing barriers to growth.

Keywords
Mitigation • Greenhouse gas emissions • Nationally appropriate mitigation actions (NAMAs)

Introduction

Climate change seriously compromises food security in some of the least developed countries, and there is an urgent need to enhance local adaptive capacity to minimize impacts and to maintain the required levels of food production (Rosenzweig and Tubiello 2007). Agriculture is also a significant source of greenhouse gas emissions, estimated to be around 10–14 % of the global total (Smith et al. 2007a), and it is the largest source of non-CO_2 greenhouse gas (GHG) emissions (De Pinto et al. 2013). To meet the demands of a growing world population, agricultural production also needs to grow, and in the absence of a step-change in the emissions intensity per unit product, this will almost inevitably lead to an increase in GHG emissions and in the sector's contribution to climate change (The Meridian Institute 2011). Assuming the sector can adapt, one of the most important areas where trade-offs might occur in coming decades is between GHG mitigation and food security.

Recent research has shown that agriculture offers significant mitigation opportunities. Smith et al. (2007b) estimate the global technical GHG mitigation potential for agriculture by 2030 to be about 5,500–6,600 Mt CO_2-eq. per year, with around 70 % of this potential thought to be in developing countries (CCAFS 2012b) and much of it potentially achievable at low cost. But realizing this potential will be challenging since under UNFCCC, non-Annex 1 (including most developing) countries do not have to subscribe to binding emissions targets, and even if they did, agricultural emissions are a particularly complex source to regulate in all contexts. Some countries such as Brazil have identified potential business opportunities in undertaking mitigation actions as part of an agenda to maintain a business edge in important livestock export sectors (BMA 2010). But the mitigation agenda also opens the potential for global aid transfers to affect low-cost mitigation in lower-income countries that could be convergent with development objectives. Agriculture is a conduit for affecting the well-being of a large proportion of the world's poorest. But it is also biophysically heterogeneous and institutionally diverse between countries and regions, conditions that complicate the definition of climate-smart interventions. Nevertheless, agricultural systems can be better designed to include farm management measures that combine complementary mitigation, adaptation, and food security or poverty alleviation outcomes. These can build on practices and technologies that are already available but need to be tailored to specific contexts including smallholder systems that characterize the sector in many developing countries. A key point is that these actions must offer a net benefit to farmers and be easily incorporated within farm practice. But mitigation actions are also likely to require incentives to help farmers adapt their practices. These incentives should provide demonstrable benefits in order to be successful.

Agriculture is the main economic activity in Malawi (Malawi Government 2011a). Food security has been a government strategic priority for the last few decades, and sectoral policy has been strongly focused on increasing food security at the household level, via improving access to essential inputs (Malawi Government GoM 2011b). Rain-fed agriculture practiced by the majority of smallholders is particularly vulnerable to climate change and the increasing incidence of droughts and erratic rainfall (99 % of 3 million ha of agricultural land in Malawi are rain dependent; FAO 2011).

Changing weather patterns have led to an increase in food security risks (Global Facility for Disaster Reduction and Recovery 2011), with the country applying for an emergency food relief as a result of the droughts in 2001 and 2005.

With the climate threat, Malawian farmers need to diversify their agricultural practices in order to have access to a reliable income stream and to maintain food security. The dairy sector is ideal for this, since it is less weather dependent than arable cropping. Assisting the development of the dairy industry in Malawi could have a positive impact on the livelihoods of the rural population which is the poorest in the country.

Despite the present danger of climate change in Malawi, there is concern that the policies and measures needed to reduce greenhouse gas emissions may impede the country's economic growth. The main challenge therefore is to control greenhouse gas emissions without negative impacts on the economy (van Asselt et al. 2010). Agricultural adaptation and (pro-poor) mitigation agendas are thus convergent in a country like Malawi, which offers a context to explore so-called climate-smart interventions. These can be defined to encompass actions that will help implement these technologies on the ground, or via, for example, policy interventions at the national level or via regional projects (e.g., supply chains) that can nevertheless deliver local benefits. The remainder of this chapter reviews issues of mitigation in the dairy sector and reflects on synergies with increasing food security and adaptation. It considers the development of a potential financing mechanism – agricultural nationally appropriate mitigation actions (NAMAs) – in the dairy sector. The chapter is structured as follows. Section "Background" provides background on the links between animal agriculture and climate change. It describes the current situation in the Malawian dairy sector and outlines potential opportunities for the development of dairy sector NAMAs. Section "Materials and Methods" provides information on survey data collected to understand farming practices and attitudes to climate change and presents results and discussion. Conclusions and implications are discussed in section "Results and Discussion."

Background

The Role of Livestock in Climate Change

Livestock are a significant source of GHG emissions including the largest source of global methane emissions from manure and enteric fermentation and N_2O from manure. Both gases have global warming potentials considerably higher than CO_2. In a comprehensive life cycle assessment (LCA), the Food and Agriculture Organization of the United Nations (FAO) has estimated that the sector contributes approximately 18 % (7.1 billion tons of CO_2 equivalent) of total GHG emissions (FAO 2006). A growing world population, predicted to reach 9 billion by 2050, will lead to an increase in the demand for livestock products with the corresponding increase in GHG emissions (Gerber 2010). The increase in livestock populations is predicted to happen mainly in the developing world, where there are currently fewer opportunities for emissions mitigation. The impacts of the increase in food production on climate change are likely to be significant. Adopting mitigation and adaptation strategies that simultaneously reduce the worst impacts of climate change on the livestock-based systems, while reducing the contribution of these systems to climate change, is therefore essential.

Within the livestock sector, rapid growth in dairy production is significant in terms of its impact on climate change and the environment. FAO estimated that in 2007, the contribution of global milk production, processing, and transportation to total anthropogenic emissions (excluding meat) was estimated at 2.7 % of total anthropogenic GHG emissions reported by IPCC (FAO 2010). The study shows that emissions per unit of milk product vary greatly across regions, with the highest emissions estimated for sub-Saharan Africa (SSA) with an average of 9.0 kg CO_2-eq per kg fat and protein-corrected milk (FPCM) at the farm gate. This compares to a global average estimated at 2.8 kg CO_2-eq (FAO 2013c). This disparity exists because of low protein production in SSA – ruminants have a very high emission intensity and low protein output (i.e., low milk production) leading to higher emissions per kg of milk in SSA than in North America or Western Europe (FAO 2013c).

But there are challenges in terms of designing interventions to redress this difference. Firstly, relative to other sectors (e.g., transport and energy), emission mitigation in agriculture is biophysically more complex and dependent on specific farm conditions. Moreover, trying to address the actions of millions of smallholders confronts behavioral and socioeconomic barriers that need to be understood in order to facilitate monitoring and verification of emission reductions.

Smallholders and Climate-Smart Practices

Smallholder agriculture is still the main economic activity in much of SSA, the livelihoods of millions being closely linked to farming (Pye-Smith 2011). Economic vulnerability is influenced by the quality of the natural resource base.

But smallholders are often unable to practice sustainable land management, either due to a lack of resources or know-how (Havemann and Muccione 2011).

Smallholder systems can potentially play an important role in both mitigation and adaptation to climate change. Whereas they may be inclined to perceive private benefits to adaptation, smallholders are unlikely to be motivated to reduce emissions without demonstrable net benefit or an incentive (Havemann and Muccione 2011). This is particularly so if such action requires a change from current practices. Net benefits can be tangible, for example, an increased profit from their agricultural activities achievable in a relatively short time frame, risk reduction, or payment for environmental services (PES), the latter involving cash payments to the smallholder to take part in conservation activities. Benefits linked to mitigation can also be indirect, such as access to training programs and institutional support, for example, through cooperative organization, extension services, and increased tenure security (Havemann and Muccione 2011).

Further, even though a failure to reduce agricultural GHG emissions would put future food security at risk, no government will adopt measures to reduce greenhouse gas emissions if they threaten a nation's current ability to feed its population (Pye-Smith 2011). The main challenge is to increase food production without increasing (or even reducing) greenhouse gas emissions from agricultural activities. Thus, the recent focus on climate-smart agriculture (CSA), a relatively new term that describes a range of practices that could increase food production, helps farmers to become more resilient to climate change and reduce emissions of greenhouse gases (Pye-Smith 2011). FAO (2012) define "climate-smart" technologies as those delivering multiple benefits, specifically, "food security and development benefits together with climate change adaptation and mitigation co-benefits."

The implementation of CSA does not presuppose a unique role for smallholders, and the challenges of monitoring actions on thousands of holdings add substance to arguments about the relative inefficiency of small-scale production (Collier and Dercon 2009). But smallholdings occupy large areas of land offering potentially cost-effective mitigation potential, and associated financing offers the potential for poverty alleviation. Unlocking this through climate-smart practices will require considerable investment, institutional and financial support, and capacity building. In many countries, these climate-smart practices can potentially be developed under NAMAs.

NAMAs as a Financing Mechanism for Mitigating Climate Change

To date, agricultural mitigation has not been a focus of international negotiation in developed or developing countries. The costs related to the adoption of mitigation practices, as well as potential difficulties associated with the monitoring, reporting, and verification (MRV) of mitigation measures all contribute to maintaining agriculture's position as a non-priority sector for climate change mitigation (FAO 2013b).

Recognizing the mitigation potential available in non-Annex 1, the Bali Action Plan (UNFCCC 2008) following COP 13 introduced a funding modality that potentially allows developing countries to propose voluntary mitigation actions termed NAMAs, which may be verified for potential bilateral or multilateral funding. NAMAs can be described as actions that contribute to the economic development of the country without contributing further to climate change or, indeed, reducing GHG emissions from a given sector (Wang-Helmreich et al. 2011). UNFCCC (2010) describe NAMAs as voluntary mitigation actions undertaken by developing countries "in the context of sustainable development, supported and enabled by technology, financing and capacity building, in a measurable, reportable and verifiable manner, aimed at achieving a deviation in emissions relative to "business as usual" emissions in 2020" (CCAFS 2012b).

Three main types of NAMAs have been described: unilateral NAMAs involving actions that a country plans to pursue for reasons other than reductions in GHG emissions; conditional/supported NAMAs that would only be agreed by a developing country if developed countries provide financial or technological support; and credited/market-oriented NAMAs that can generate credits that will be sold on the global carbon market (CCAP 2009). Each of these three types of NAMAs can be project based, sector based, or at a national scale.

NAMAs are expected to be assessed based on the performance and to be linked to real and measurable emission reductions. Apart from unilateral NAMAs, the other two types involve high costs and stringent MRV requirements. Where NAMAs are implemented with international support, they are subject to both national and international measurement, reporting, and verification (CCAFS 2012a). There are no defined rules for international support to NAMAs, but it is clear that public sector finance alone will not be able to fully finance NAMAs in developing countries, and private sector involvement will be necessary (CCAFS 2012a).

Although NAMAs are expected to contribute towards mitigation, they should not be independent of a developing country's national priorities, such as poverty alleviation and economic growth (Upadhyaya 2012). This raises an obvious question about the definition of potential agricultural sector NAMAs that can be anticipated as a promising instrument for advancing climate change abatement policies (FAO 2012).

Agricultural NAMAs can provide additional resources for agriculture with multiple benefits, including adaptation, food security, and sustainable development, i.e., they should not be considered in isolation as a stand-alone mitigation tool. Adding further to the related nomenclature, some commentators suggest that NAMAs may become Nationally Appropriate Climate-Smart Actions (NACSAs) and, potentially, be incorporated in the country's National Adaptation Plans (NAPs). The question is how to ensure that these multiple objectives are achieved simultaneously (Upadhyaya 2012).

Some countries have been proactive in proposing agricultural NAMAs, motives of which vary. NAMAs are regarded as an entry point for a transition to a low-carbon development or green growth path, or they are seen as an opportunity to access new sources of finance for sustainable development; in some cases agricultural mitigation is needed to meet voluntary national emission reduction. To date, mitigation actions in the agricultural sector are mentioned in 40 % of NAMA submissions (21 out of 55 country submissions) to the UNFCCC Secretariat, mainly by African countries (CCAFS 2012b; FAO 2013b). These focus on agricultural technologies and practices, including the restoration of degraded grazing land, the use of improved seed varieties, agroforestry, application of composts, and minimum or no-tillage, all of which provide some ancillary adaptation benefits. Increasing agricultural productivity is at the center of the majority of proposed NAMAs.

Malawi has been active in exploring the potential for agricultural NAMAs, with a 2012 UNFCCC submission proposing actions on biogas for energy and manure waste management (Malawi Government 2011b, 2012a, b). As yet, there is no specific analysis to guide the potential inclusion of the dairy sector though its mitigation potential is recognized.

The Development of the Dairy Sector in Malawi

The Malawian dairy sector is still in its infancy and makes a small contribution to the livestock subsector (livestock accounts for approximately 10 % of the country's agricultural gross domestic product (GDP) (National Statistical Office of Malawi 2012); but the exact contribution of the dairy sector to the GDP has not been estimated). The sector mainly relies for milk supply on smallholder farmers who normally own between one and four dairy cows (Chitika 2008). Most dairy farmers are situated around the three large cities in Malawi: Blantyre (the Southern Region), Lilongwe (Central Region), and Mzuzu (the Northern Region), where they are organized into milk bulking groups (MBGs) (see Fig. 1). These groups are local farmer associations with cooling centers where milk is centrally collected from farmers within a radius of 8–10 km.

Recent data suggest that there are currently around 16,000 smallholder dairy farmers in the milk-producing regions (CISANET 2013). In 2012 these smallholders produced around 13.5 million liters of milk marketed through the formal channel (data received from three main milk-producing associations in Malawi), 91 % of which was produced in the Southern region. A further 16.5 million liters is estimated to be produced in the informal sector, which is currently the dominant marketing channel (Imani Development Consultants 2004). The two channels differ in the way milk reaches the final consumer. In the formal sector, milk is processed and sold to the consumer via retail outlets; informal sector milk is sold raw (and often diluted) to either vendors or direct to consumers (Chitika 2008).

Official estimates show an increasing trend in the number of dairy cattle in the country partly through import of animals into the country (see Fig. 2). Banda et al. (2012) estimate that there has been a 65 % increase in dairy cattle between 2004 and 2010, mainly as a result of government and aid donor support.

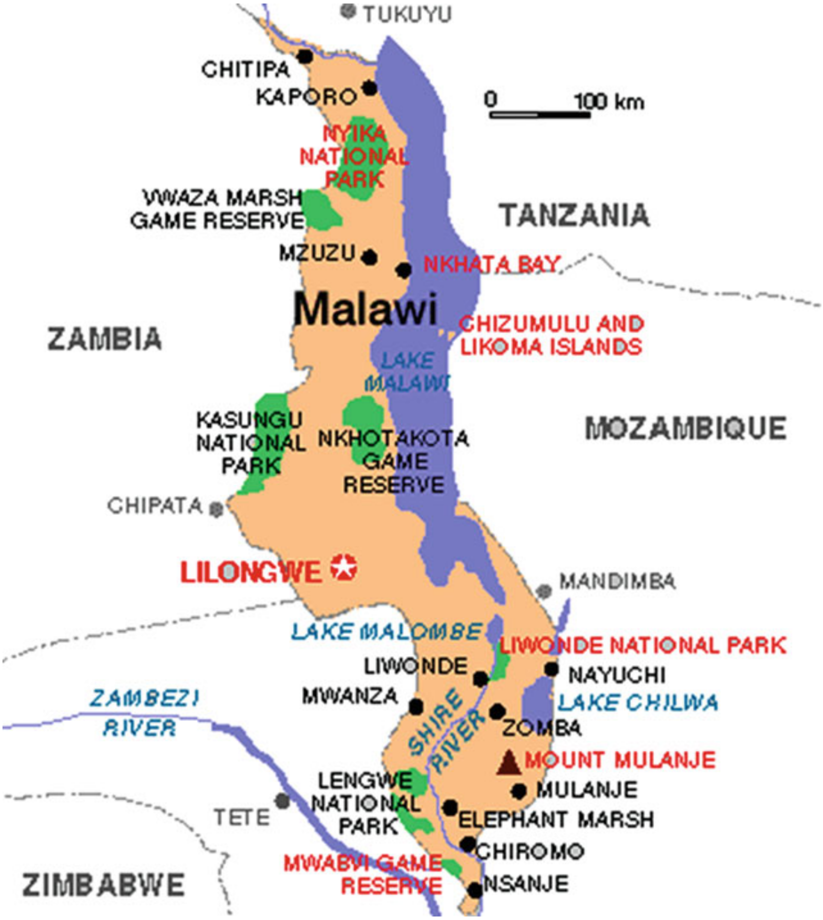

Fig. 1 Dairy production regions (Source: FAO, http://www.fao.org/ag/AGP/AGPC/doc/counprof/malawi/Malawi.htm)

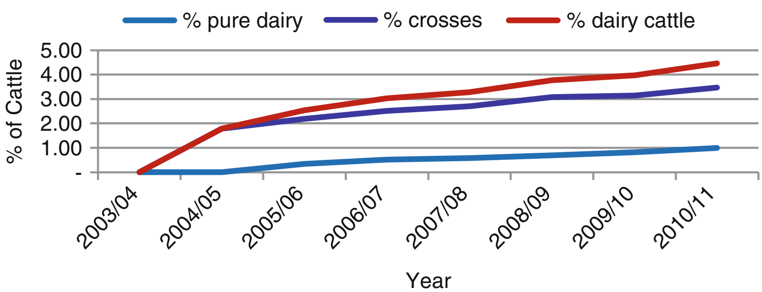

Fig. 2 Increasing trend in dairy cattle numbers in Malawi since 2003 (Source: USAID 2012)

Data provided by the Ministry of Agriculture and Food Security of Malawi shows that milk production has been steadily increasing in recent years (FAO 2011). This can be attributed to increasing cattle numbers, a result of development efforts, and a desire of many smallholders to diversify out of standard agricultural practices and to earn a reliable income.

Despite the growth in dairy cattle numbers (currently comprising about 5 % of the national cattle population), only 13 % of smallholder farmers in Malawi own cattle (CISANET 2013), reflecting a lack of emphasis on livestock in official agricultural strategies and policies. Moreover, poor performance in the arable sector has caused many farming families to expand their arable cultivation into areas traditionally grazed by livestock (CYE Consult 2009).

Diary productivity (i.e., milk output per cow) is generally low. Nakagava (2009) estimates the average production per day between 5.7 and 9 l per cow, mainly produced by the local Zebu breed. This is mainly due to the lack of good husbandry practices, long calving intervals, lack of good quality feed, and insufficient veterinary and artificial insemination (AI) and extension services (CISANET 2013). Productivity depends on breed choice with nonnative Friesians being most productive but also on the management quality (Chagunda et al. 2010). Zimba et al. (2010) estimate that even though individual farmers produce about 7 l of milk a day on average, there is a potential to produce up to 40 l by changing current management practices.

Milk consumption in Malawi is low, estimated at 4–6 kg/capita/year (Tebug 2012). This is much lower than the Africa average of 15 kg/capita/year and significantly lower than 200 kg/capita/year recommended by the World Health Organization (WHO) and FAO (Banda 2008). In other sub-Saharan countries, such as Kenya, milk consumption is 95 kg/capita/year with smallholder dairy farming playing a key role (Tebug 2012). Low consumption is partly explained by the limited supply of milk (CYE Consult 2009), leading to some of the highest consumer prices for milk products in Africa (The Dairy Task Team 2010; USAID 2012).

Tebug et al. (2012a) suggest that factors like population and income growth, plus dietary change and urbanization, have led to increased milk demand in Malawi in the recent years, consumption increasing by 40 % between 1980 and 2002 (FAO 2011). Malawi's population is predicted to grow from 15.4 million to 37 million by 2050 from its current level (Malawi Government 2012a, b; The World Bank 2012), meaning that the demand for dairy products is likely to increase further. There is thus a clear need to address barriers to sector development. But increasing milk production by increased herd size in the smallholder sector or via increasing the number of smallholder farmers diversifying into the dairy farming, while in the national interest, will almost inevitably lead to an absolute increase in GHG emissions. Introducing good farm management strategies to help reduce GHG emissions is therefore a potential entry point for climate-smart NAMA support that moves the country onto an emissions trajectory without compromising its development goals.

Opportunities and Challenges for Developing Dairy Sector NAMAs

Dairy is considered a key investment sector within agriculture for the Government of Malawi (MIPA 2011), and dairy development has become a government priority and a flagship of the livestock sector aimed at enhancing household livelihoods. Most recently, the dairy sector in Malawi has also been widely supported and promoted by international donors and NGOs that have developed business models for upscaling breeding, livestock management, value chain, and risk insurance support.

In capitalizing on the synergies in dairy sector development, it is important to recognize and reconcile the key policy drivers and extant constraints affecting sector development. Economic development and livelihoods are the key objectives of agricultural development. Malawi's National Dairy Development Programme (NDDP) aims to contribute to improved livelihoods of both producers and consumers, as well as provide economic benefits for the national economy. NDDP aims to increase the total milk production in Malawi from around 30,000 metric tons to 61,000 t per annum by 2017 (Malawi Government 2011b). As a result, it has been calculated that with current farm levels emissions will double with doubling total milk production (Wilkes et al. 2012).

Like any non-Annex 1 country, Malawi is unlikely to adopt mitigation measures if they compromise food security and unless there is some form of international compensation. Further, current lack of economic incentives for livestock farmers in Malawi to reduce GHG emissions means that any mitigation which lowers emissions at the expense of productivity is certain to be nonviable (CCAFS 2012a). These conflicting objectives can potentially be reconciled in the dairy sector by a focus on smarter production practices and sector development.

A number of constraints have been reported to the development of the dairy sector in Malawi at the farm level (Tebug et al. 2012b). These include poor farm management practices, including inadequate feed and feeding technologies often leading to low production of milk, and poor manure management, as well as poor animal health and high mortality rates of the dairy cattle (Sindani 2012). Addressing these barriers offers opportunities for pro-poor development in the sector, through improving food security (i.e., availability of safe and affordable dairy products) and smallholder incomes.

Dairying can provide a regular income with monthly payments and relatively easy work often undertaken by women. Smallholders can earn on average more than \$300/year from milk sales (USAID 2008), providing regular and relatively high income, as well as a diversification of household risk.[1] This is because income from dairying is less affected by the change in weather patterns compared to maize and tobacco. Dairying has an added advantage of being successfully practiced in

[1]According to CYE Consult (2009), one cow gives a monthly profit that is three times the minimum wage (MK317 per day as of 1 July 2012).

areas with limited land, less labor supply, and even in poor rainfall environments (CISANET 2013).

Dairy sector NAMAs can potentially be an important option for accessing climate finance opportunities directed at scaling up best practices in agriculture. Compared to other sectors, agriculture has an advantage in that many mitigation technologies and practices are already relatively well understood and available (CCAFS 2012b; Ogle et al. 2013). But important knowledge gaps persist in terms of the technical applicability of measures at significant scale across smallholdings. Furthermore, there is currently little information on the acceptability of measure implementation by low-income householders. The remainder of this chapter provides survey evidence exploring these elements.

Materials and Methods

To explore NAMA options, an extensive survey of 460 smallholder dairying households in all three milk-producing regions in Malawi was carried out in February 2013. The survey sought insights into the relationship between climate change and smallholder dairying in Malawi. A more specific aim was to explore mitigation and adaptation practices that can inform national policies and potential NAMA development.

The questionnaire contained 165 questions and included elements on dairy farm management and milk production, the dairy marketing chain and market access, and access to animal health and livestock extension services. Further sections sought information on household structure, animal numbers and breeds kept, milk sales, and feeding methods and constraints faced in production. In essence, the aim was to explore both on-farm and post farm gate issues that influenced production and could become potential entry points for NAMA design.

A sampling strategy was developed using information provided by the MBGs and the University of Malawi and covered selected MBGs in the three milk-producing regions – Mzuzu Milk Shed Area in the Northern region, Lilongwe Milk Shed Area in the Central region, and Blantyre Milk Shed Area in the Southern region.

It considered only smallholder farmers who were members of a MBG, the majority of the farmers in Malawi. Inactive MBGs (those no longer actively involved in marketing milk) were excluded from the sample. Stratified random sampling was used for the survey, based on the available farmer lists, with the number of female farmers in the milk shed areas taken into account to ensure the gender balance. Surveys were administered over a period of 3 weeks by trained enumerators and supervisors split into three groups. The team ensured quality of the data through a regular review of all questionnaires by the supervisors and research assistants after each data collection day. Further data were collected through direct observation and key informant interviews.

In terms of mitigation options, the survey focused on baseline practices related to practical measures identified in the IPCC Fourth Assessment Report

(Smith et al. 2007b), specifically livestock feed practices, including grazing management, pasture improvement, manure management, and biogas production from manure.

Results and Discussion

NAMA Development: Baseline Survey Evidence from Smallholder Agriculture

Key response data on relevant survey questions are summarized in Table 1.

The survey observations point to a number of key observations relevant to NAMA design.

Pasture Production and Feed Management

Feeding practices are clearly relevant to animal productivity and hence emissions, but current inefficiencies have much to do with limited plot sizes and the use of cut and carry forage of low digestibility and customary tenure systems working against any improvement incentive. Pasture improvement and hay making are not often practiced.

Even though supplemental feeding is becoming more common among dairy farmers, with maize bran being the most common supplement, the price of dairy mash and other supplements as well as the availability of minerals and molasses constrain regular use. A very small proportion of the households use minerals or molasses.

Increased use of crop by-products and feed supplements has been suggested as an economical way of ensuring access to adequate supplies of nutrients (Mtimuni 2012). Capacity building of farmers on locally available and potential feed resources and the importance of these in improving production efficiency will be essential.

Size of Herd and Milk Production

A revealing survey finding is that a high percentage – >80 % – own pure breed cattle rather than cross or local Zebu cattle. The latter breed is better adapted to local conditions, but milk production from Zebu is lower than from crossbreed or pure breed cows, which largely explains farmer breed preferences. Around 80 % of the sample also own only one animal, thus limiting production with obvious implications for the types of cattle-related investments they can be expected to make.

The majority of respondents think there are significant constraints on production; the most important being low milk yield and market prices, high price of concentrate feed, as well as animal disease including infertility.

Manure Management and Biogas Production

Manure is an important source of methane, whereas manure excreted during grazing, as well as emissions from livestock sheds is one of the most important

Table 1 Main survey questions and summary observations

Question	Proportion of respondents	Observations on current constraints and barriers
Pasture *production and feed management*		
Pasture size	50 % of surveyed farmers do not own pasture land, and 90.9 % of those who do own areas of less than 1 ha	Absence of established pastures leading to common feed shortages
What type of grazing do you practice?	95.4 % of respondents practice zero grazing (or cut and carry) feeding regime	Low digestibility grass/forage leading to high methane emissions
Do you make conserved feeds (e.g., hay)?	59.5 % do not make conserved feeds	Feed is not efficiently utilized as feed conservation practices such as hay making are not often practiced leading to frequent feed shortages
Do you regularly experience a shortage of feed?	50.0 % of respondents regularly experience shortage of feed	Feed shortages are a significant limitation to increasing animal productivity
Do you have enough fodder for your animals for the whole year?	53.4 % of respondents do not have enough fodder for their animals	Lack of fodder can have a significant impact on animal productivity
Do you purchase crop by-products during the year (as feed for the dairy animals)?	78.1 % do not purchase crop by-products	Crop by-products contribute to the higher yields in dairy cows leading to reduced emissions per kg of milk
Do you use concentrated feed?	Only 35.6 % of farmers use concentrated feed	Concentrated feed improves yields and thus reduces emissions per kg of milk
Milk production		
Do you plan to increase the amount of milk you produce?	89.5 % of respondents plan to increase milk production, the majority via producing or buying more feed	Farmers appreciate the importance of improved feeding practices for increasing milk production
Do you think there are significant constraints to dairy production on the farm?	94.5 % of respondents think there are significant constraints on production, the most important being low market prices of milk, low milk yield, high price of concentrate feed, and prevalence of animal disease or infertility	High price of concentrates and supplements reduce productivity and contribute to higher emissions as animals then rely on less easily digestible grass from pastures or *dambos* (*hydromorphic areas owned by the whole community*). Low milk prices indicate how supply chain structure (i.e., post farm gate) also influences production decisions

(*continued*)

Table 1 (continued)

Question	Proportion of respondents	Observations on current constraints and barriers
Manure management		
Most common manure storage system?	Dry lot/heap storage used by 54.7 % of farmers; pit storage – by 37.7 %	Uncovered manure heaps are a source of CH_4 emissions that can be reduced by changing manure management system
Biogas production from manure?	The majority of farmers do not produce biogas	The technology requires high up-front costs but can be greatly beneficial to farmers and help reduce emissions
Agroforestry		
Are you involved in any agroforestry work?	59.5 % of all respondents are not involved in any agroforestry work	Lack of know-how and lack of awareness of the benefits of agroforestry (such as providing fuel and feed for the animals) are the main reasons for farmers not practicing
Animal health		
Did you see any diseased animals on your farm in the past 12 months?	43.8 % have seen diseased animals on their farm in the past 12 months. 12 % of the respondents have experienced dairy cattle deaths	Poor animal health is a major issue, mainly associated with lack of knowledge and training in animal health
Supply chain		
Do you have difficulties selling your milk?	91.2 % of farmers experience difficulties when selling their milk; 70 % of these – due to the poor quality and low price of milk	Poor quality milk often leading to milk wastage is mainly due to the lack of the refrigeration facilities at dairy farms, milk souring while being delivered to the MBG, because of the distances and fresh milk souring after having been delivered to the MBG as a result of frequent power cuts. This, coupled with the low milk prices offered by the dairy processors irrespective of the season, does not provide incentives for farmers to produce more milk
Do you have your milk rejected by an MBG?	66.1 % of respondents regularly experience their milk being rejected by the MBGs	Even though farmers might deliver good quality milk to the MBG and milk is initially accepted, it may later be rejected by the processors if it gets sour due to frequent power outages and generator break downs. This wastage encourages some farmers to sell outside the formal market

(*continued*)

Table 1 (continued)

Question	Proportion of respondents	Observations on current constraints and barriers
Do you experience delays in getting paid for the milk sold?	88.6 % experience delays in getting paid for the milk, with 48.5 % experiencing delays of up to 1 month	Delays in payments often lead to farmers turning to the informal market for selling their milk, as the price is paid up-front. This leads to a significant amount of milk being sold outside the formal channels
Are there any incentives in your local MBG for delivering milk in low season?	93 % of all MBGs do not have any incentives in place to reward farmers delivering milk in low season or producing higher amounts of milk	The absence of incentives often makes farmers sell in the informal market, where the price paid per liter is higher
Are there any dairy cooperatives (apart from MBGs) that you are a member of?	More than 99 % of farmers do not belong to any dairy cooperatives	Lack of farmer organizations makes farmers more vulnerable and unable to negotiate better payment conditions with the dairy processors

sources of the N_2O. The most common manure storage system is dry lot – followed by pit storage. More than 80 % of this manure is produced when the cattle are housed.

CH_4 emissions from manure management greatly depend on the time manure is stored inside sheds or *kholas* or in outdoor manure stores (Chadwick et al. 2011). The majority of surveyed farmers store manure between 6 and 8 months before use or disposal. Removal of manure from animal housing into outside storage is infrequent, and the storage areas are normally not covered. More than 90 % of farmers do not cover manure with any material, and more than 40 % mix it with other material. It has been shown that emissions from cattle housing can be reduced through a more frequent removal of manure to a closed storage system (Monteny et al. 2006).

Unsurprisingly for this sample, the majority of surveyed farmers do not produce biogas on their farms, even though only 19 % of surveyed farming households have access to electricity (including solar power), and biogas production can generate energy (heat or electricity) and produce residual fertilizer. However, digesters involve significant capital costs, and finance and farmer cooperation are barriers that would need to be overcome.

Agroforestry Practices

Agroforestry is important both for both mitigation (carbon sequestration, improved feed, and consequently reduced enteric methane) and for adaptation (improving the resilience of agricultural production to climate variability by using trees to intensify and diversify production and buffer farming systems against hazards; FAO 2013a). Shade trees reduce heat stress on animals and help increase productivity.

Trees also improve the supply and quality of forage, which can help reduce overgrazing and curb land degradation (Thornton and Herrero 2010). Furthermore, crop by-products and co-products from agroforestry can be used as low-emission feeds for cattle.

More than half of respondents were not involved in any agroforestry work; the majority of these mention lack of knowledge/training or know-how as the main reason for not practicing agroforestry.

Animal Health

The survey revealed that nearly half of all respondents had detected diseased animals on their farm in the previous 12 months leading to cattle deaths on 12 % of farms.

Better nutrition, improved animal husbandry, regular animal inspection, and the use of antibiotics can improve reproduction rates and reduce mortality (Tebug 2012). All of these measures can therefore increase animal productivity at relatively low cost.

Supply Chain Efficiency

Some of the most revealing survey responses related to supply chain relationships. The survey revealed that low milk procurement prices and quality requirements are a considerable barrier to participation in formal milk marketing by smallholders. The current supply chain structure means that smallholders are reliant on conditions for quality and prices set by the MBGs. Since the latter do not return milk that fails a quality threshold, there is a risk for small producers who lack the equipment and expertise to reach these thresholds. On the other hand, reliance on informal marketing does not always guarantee higher prices or a more regular outlet for produce. An added disadvantage is that smallholders involved in the informal marketing are unable to access credit as a basis for livestock improvement (Sindani 2012).

There is also a lack of farmer organizations/cooperatives at the level below Milk Bulking Groups (CISANET 2013). Survey results show that the majority of all respondents are not part of any dairy or farmer cooperative, mostly due to the lack of these. The establishment and participation of effective and representative farmer organizations that are able and willing to communicate on behalf of their members are essential. But establishing such groups requires support and capacity development.

Overall, the survey indicates that supply chain efficiency is as important as on-farm measures for increasing productivity, hence reducing emissions. A NAMA approach that considers the entire dairy supply chain is essential.

Potential Dairy Sector NAMAs

Findings summarized in the previous section indicate considerable scope for NAMA design, with mitigation options available along the entire supply chain. The most immediate and low-cost options are likely to be targeted to feed production, enteric fermentation and adopting composting, improved manure handling and storage, as well as adoption of different application techniques. Most of these will not require any capital costs, but farmer training and knowledge dissemination will be essential.

Most on-farm interventions aim to improve basic farm productivity and resource use. For example, the use of improved feeding technologies, manure management (e.g., composting), and agroforestry are readily available for implementation and have been successfully trialed in other parts of sub-Saharan Africa (FAO 2013b).

It has been shown that a relatively small change in the efficiency of dairy feeding can have a major effect on animal productivity and farm profitability (Gerber et al. 2011). A feeding intervention NAMA will need to focus on capacity building for farmers on the benefits of introducing improved feeding techniques.

Improved manure management via deployment of technology for biogas-based electricity generation is also a promising basis for a NAMA helping to reduce CH_4 emissions from manure and provide smallholder households with much needed energy. Introduction of this technology would require credit agencies or donors to cover costs for purchasing bio-digesters, as well as training of farmers on biogas production. In this regard the NAMA objective overlaps with that of the Clean Development Mechanism (CDM), which is a longer established financing mechanism that can be used for biogas energy. Most recently CDM funding was used, for example, in the Nepal Biogas support programs (Doyle 2013). Experience with biogas CDM projects has demonstrated practical MRV approaches that can clearly facilitate NAMA development (FAO 2013b).

An agroforestry NAMA will need to focus on knowledge dissemination, awareness raising and training of farmers on the benefits of agroforestry for the productivity of the farm and income generation, provision of seeds to farmers, and follow-up work with farmers to achieve returns in terms of improved resilience and increased household incomes. Again, because of overlapping objectives, payment for environmental services mechanisms could also be explored to encourage farmers to participate in agroforestry practices. But like PES mechanisms, institutional (e.g., legal and policy) reforms would be necessary to foster the development of agroforestry and recognize its contribution to national development and mainstreaming of agroforestry in national policies.

Animal health intervention NAMA should focus on farmer training on animal health-related issues and provision of higher-quality extension advice and artificial insemination and veterinary services. Poor farm management practices may be partly addressed by improved access to information including breeding and veterinary services; the latter could have a significant impact on reducing animal mortality.

Overall, improving the efficiency of the dairy supply chain is an explicit barrier emerging from the survey, since one of the most important constraints to increasing productivity is low price paid for milk, which is an underlying reason for the lack of investment in animal productivity, thus locking farmers into a downward spiral that ultimately retards investment in animals as a capital asset. These barriers can be

Table 2 Proposed NAMAs for the smallholder dairy systems in Malawi

Sector	Proposed NAMA	Benefits to farmers	Constraints
Feeding practices	Use of improved feed and feeding technologies, increased use of crop by-products, supplements and concentrated feed	Higher yields, improved animal health	High cost for purchasing concentrates, supplements, and vitamins. Lack of established pastures to grow feed with a low-carbon output
Manure management	Activities aimed at composting, improved manure handling and storage	Higher crop yield if using manure as a fertilizer	Lack of knowledge and incentives
Biogas production	Provision of grants to farmers to purchase biogas digesters, training and follow-up support	Improved farmer livelihoods through access to energy	High capital costs, lack of knowledge and incentives
Animal health	Targeted farmer training on maintenance of animal health and improved animal husbandry	Improved reproduction rates, reduced mortality, increased productivity	Lack of knowledge and know-how, poor animal management practices, limited access to extension and veterinary advice
Agroforestry	Provision of training on agroforestry practices targeted at dairy farmers, provision of seeds and follow-up support	Improved feed and resilience, increased animal productivity	Limited land, lack of knowledge and know-how
Supply chain	Organizing dairy cooperatives/farmer organizations at a level below MBG level	Empowering farmers to negotiate higher milk prices, access to credit to purchase more animals or feed, accessing high-quality extension advice as a group	Lack of knowledge and know-how, inertia

overcome with specially targeted supply chain and policy interventions, such as extension work, farmer training, and financing mechanisms, including improving access to credit and payment for environmental services. Supply chain interventions can offer verifiable interventions that may be amenable to coordinated government and donor interventions. This is paramount for sector development and increasing production as current oligopolistic structure of bulking groups is a potential target for concerted intervention between government and donors.

The initial supply chain NAMA could focus on organizing the dairy cooperatives where dairy farmers will have a stronger collective voice and can negotiate with the MBGs and, directly, with the dairy processors regarding the prices paid per unit of milk and reducing wastage, access to feed and feeding supplements, and negotiate with the credit organizations with regard to obtaining credit for dairy farming. Higher prices paid for milk will encourage farmers to increase investment in dairy farming and to improve their knowledge of dairy farming and management practices. Furthermore, it is important for any supply chain NAMA to focus on improving links between multiple stakeholders within the supply chain and providing greater coordination among the different stakeholders.

It is important to stress that from both national and international funders' perspectives, a robust system of measuring, reporting, and verifying is essential for effective monitoring of the NAMA implementation and for assessing its impact in terms of greenhouse gas emissions reductions, cost-effectiveness, and other co-benefits (UNEP 2013).

Proposed NAMAs are summarized in Table 2 below. At the current time, it is important to improve the evidence base to demonstrate that measure implementation can reduce emissions and improve or maintain smallholder livelihoods. This might require specific farm-scale modeling of identified options. Even then some of the identified options, such as using more concentrated feed or biogas production from manure will require financial assistance to implement, and capacity building will be necessary to make farmers more aware of the potential benefits of these strategies.

Conclusions

Current farm management practices in the smallholder dairy sector in Malawi offer significant options for agricultural-based NAMAs that could potentially reduce emissions and improve livelihoods. The smallholder survey found a number of farm management practices that could be modified to be climate smart and potentially funded under a NAMA modality. These options can initially be implemented as pilot project-based NAMAs, a climate change mitigation modality that has the potential to dovetail with a range of existing development aid objectives.

But development of agricultural NAMAs requires further analysis. Specifically, the adoption of measures by farmers must be locally appropriate and clearly beneficial before behavioral change can be expected. At present, the evidence on the farm-scale profitability of measures is unproven in all cases.

Many of the available options could build on, or scale up, current practice; however, in some cases (such as biogas production), technical innovations may be required. Even though a diversity of mitigation options provides flexibility, it creates extra challenges in measuring, reporting, and verification.

Furthermore, the potential mitigation strategies need to be thoroughly assessed in terms of their emission reduction, additionality, and cost-effectiveness. Specific interventions might only make sense and achieve a net mitigation effect if greater on-farm efficiency does not instead displace emissions to other parts of the food chain.

Finally, the proximity of NAMA and climate-smart agendas suggest that the former need to be designed with clear reference to the ongoing agenda on climate change adaptation. This places emphasis on combinations of mitigation and adaptation practices adapted to specific production systems and environments (e.g., interventions addressing the management of feed, genetic resources, and manure). The potential aggregated effects that changes in farming systems may have on food security and the use of natural resources at the regional level also need to be better understood. It will be essential for the NAMA interventions to take into consideration whole production systems and supply chains, as addressing mitigation or adaptation issues requires paying attention to spillover and feedback effects along the chain.

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Prospects and Challenges of Local Community Adaptation to Climate Change in Developing Countries: The Case Study of Malawi

Sane Pashane Zuka

Contents

Abstract

In response to global climatic change and variability, adaptation to climate change has become a widespread global policy goal. It is currently seen as a solution to the likely negative effects of climate change, especially in developing countries. However, adaptation to climate change largely depends on the socioeconomic system's adaptive capacity. In the urgency to achieve adaptation to climate change, this question has hardly been adequately explored. This chapter fills this gap by examining the prospects and challenges of community adaptation to climate change in developing countries through the case study of Malawi. The study findings demonstrate that community adaptation to climate change has the potential to stimulate and build productive local livelihood systems.

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However, its success is currently hampered by two things. First, there is lack of clear climate adaptation policy framework to guide community adaptation initiatives. Secondly, the existence of rampant household poverty and low institutional capacity makes it difficult to support community adaptation initiatives. This situation is exacerbated by unstable donor funding toward climate change adaptations. This chapter, therefore, argues that sustainable community adaptation to climate change in developing countries requires improving their social, economic, and institutional capacities.

Keywords

Malawi • Climate change • Local community adaptation • Sustainable livelihoods

Introduction

This chapter undertakes a critical assessment of the developing countries' prospects and challenges of adapting to climate change through the case study of Malawi. The chapter is motivated by the fact that in response to global climatic change and variability, adaptation to climate change has become a widespread global policy goal (UNFCCC 2007; Rohr 2007; UNDP 2007). Simply defined, adaptation is the process of deliberate adjustment in ecological, social, and economic systems in anticipation of, or in response to, actual or expected climate stimuli and effects or stresses (Stringer et al. 2009; Smit and Pilifosova 2001). It is advanced because of its potential to substantially reduce negative climate change impact and stress. Empirical evidence, however, reveals that adaptation to climate change is not automatic. It depends on systems' adaptive capacity and varies among regions, countries, and socioeconomic groups depending on their resource, technology, information, and climate change-related institutional endowments (Burton et al. 1998; Rohr 2007). Equally important, though natural and human systems have spontaneously adapted to climate change for a long time, current climatic change and variability conditions have grossly strained the coping range of the systems leading to greater physical, social, and economic losses (Huq et al. 2003). Thus, current scholarship has highlighted the need for prioritizing planned adaptation to climate change, especially in developing countries. There is increasing evidence that developing countries will bear the most effects of climate change despite contributing less to its causation (Huq et al. 2003; Bie et al. 2008; Burton et al. 1998). Current community climate change adaptation efforts are, therefore, to a greater extent designed and financed by a network of local and international governments and agencies. This trend is largely premised on the argument that local people have low adaptive capacity to climate change and variation (Action Aid 2012; ICIMOD 2012; Smit and Wandel 2006).

However, empirical evidence from a variety of climate change adaptation projects suggests mixed outcomes. While there is on the overall net gains on national level, net gains on specific local communities and groups are debatable (Actionaid 2006; Labaris 2012; Bie et al. 2008). In particular, studies have highlighted lack of clear understanding of challenges facing local communities in adapting to climate change as a major cause for unimpressive outcomes. This chapter is set to fill in this gap. This study uses Malawi, one of the least developed countries, as a case study to explore this question. Specifically, this study explores Malawi's policy and institutional framework guiding its climate change adaptation initiatives, documents and assesses the effectiveness of major climate change adaptation strategies, and explores challenges for local community adaptation to climate change. More generally, the study highlights the dilemmas of climate change adaptation strategies in achieving sustainable community adaptation to climate change. Three insights emerge: (1) there is unclear policy and institutional framework for the implementation of climate change resulting in ad hoc designing and implementation of community adaptation strategies; (2) although current climate change adaptation strategies help to build community resilience for a short time, failure to correspond the design of climate change adaptation strategies to social, economic, and institutional capacity building results in unsustainable adaptation initiatives and ushers in a community that perpetually depends on external assistance; (3) externally designed climate change adaptation strategies should not be expected to improve livelihood situations among communities of developing countries without improving their social and economic conditions.

Themes in Adaptation to Climate Change in Developing Countries

Climate change adaptation debate in developing countries can be summarized into four major themes. First, though developing countries contribute less to global climate change, they will bear the most impacts due to fewer social, technological, and financial resources (UNFCCC 2007; UNDP 2007; IIED 2011). Second, though external aid is important in climate change adaptation, placement of climate change issues affecting developing countries at a periphery of international climate change forums affects nature and intensity of climate change response (UNDP 2009; Rohr 2007). This is worsened by contested agrarian trajectory for achieving sustainable economic development in developing countries. In particular, the polarized debate on small-scale versus large-scale investment, subsistence versus commercial farming, and diversity versus intensity remain unsettled (Matondi et al. 2011). For instance, the extent to which western-based agricultural innovations can equitably benefit local community members is challenged by historical empirical evidences of bias of such innovations against the poor community groups such as women (Booth et al. 2006; Mkandawire 2009). Another important theme in climate change adaptation relates to the role of local institutions in climate change adaptation. There is a growing literature that argues that local institutions affect climate change impact by, inter alia, influencing how households are affected by climate change impacts, shaping household response to climate change, and mediating the flow of external intervention to climate change adaptation (ICIMOD 2012; Agrawal 2008). However, several academicians have criticized local institutions as being responsible for perpetuating bias and discrimination against weak and poor groups of people in the community. In line with this view, there is also increasing call for a gendered approach to climate change adaptation in order to have a sustainable impact (Rohr 2007).

Conceptual Framework

It is not debatable that the question of climate change adaptation is more serious in developing countries. A number of scholars describe developing countries, especially those in Africa, as likely to bear the most impact of climate change leading to a number of social, economic, and environmental problems (Burton et al. 1998; Kelly and Adger 1999; Smit and Wandel 2006). This view is founded on the countries' low capability to positively adjust to the changing environmental conditions. Thus, this study adopts the concept of adaptive capacity, which is defined as the potential, capacity, or ability of a system to adapt to climate change stimuli or their effects or impacts. In general, there are six major variables that determine the ability of individuals, countries, and regions to adapt to climate change, namely:

- *Economic resources* – economic assets, capital resources, financial wealth, and poverty situation
- *Technology* – the type, level, and extent of use of technology in the community
- *Information and skills* – knowledge about adaptation options, capacity to access them, and capacity to implement the suitable ones
- *Infrastructure* – the recognition and contribution of social infrastructure to adaptive capacity
- *Institutions* – the institutional environment in which adaptation takes place, including institutions of holding society together, giving it sense and purpose and enabling it to adapt
- *Equity* – the allocation and distribution of resources within society

These variables influence the adaptive capacity of a local community to positively respond to climate change by presenting or altering an enabling environment in which adaptation takes place.

Methodology

This chapter is based on data collected through four main methods, namely, household surveys, key informant interviews, focus group discussions, and extensive literature review of community adaptation to climate change in Malawi and developing countries. Key informant interviews were conducted with government officers in the Ministry of Agriculture and Food Security, academicians, nongovernmental organization (NGO) staff working in the area of community livelihoods, and local leaders such as chiefs and members of the local development committees. Household surveys were carried in three districts of Mzimba, Salima, and, while key informant interviews were conducted in seven districts, namely,, Ntcheu, Nkhata Bay, Nkhotakota, Mzimba, Karonga, and Blantyre. Thus, the study covered all the three administrative regions of the country. Secondary data involved review of government policy documents, NGO reports, international donor reports, and academic literature on climate change. The study administered a total of 120 questionnaires in three districts, namely, Mzimba, Salima, and, which were sampled based on their vulnerability to climate risks. In these districts, the study randomly sampled three extension planning areas (EPAs), one EPA from each district, namely, Luwerezi, Chipoka, and Ngabu. Simple random sampling was then used to select 40 respondents in each EPA. In addition to household survey, literature review of existing secondary data in the study area was used to complement missing socioeconomic data.

A total of 35 key informant interviews and 16 focus group discussions were conducted. Use of both quantitative and qualitative study approaches allowed triangulation of issues coming out from each approach.

Socioeconomic Characteristics of Respondents in the Study Areas

The general socioeconomic characteristics of respondents in the districts of Mzimba, Salima, and are not different from the national trends in the rural areas of Malawi. Household surveys conducted in the areas reveal that over 90 % of households predominantly depend on rain-fed subsistence farming for their livelihood. The main food crops grown in these areas include maize, cassava, groundnuts, beans, sweet potatoes, and rice. In addition to farming, about 65 % of the household in all the districts raise livestock especially cattle, goats, chicken, and pigs. Thus, local communities' livelihood platforms are highly susceptible to climate change risks due to increased incidences of drought, floods, pests, and diseases. This situation is aggravated by declining household land size across the nation. In the study areas, the average household land holding size is less than 0.5 ha. Declining household land size, driven by high population growth of between 3.2 % (Salima) and 2 % (Chikhwawa), increases poverty levels because of the strong link between poverty and landholding size in the rural areas of the country (World Bank and GoM 2006). According to NSO (2010), incidence of rural poverty in Malawi is as high as 43 %. In the sampled areas, between 79 % and 82 % of the households live below $1.25 a day. The implication of this situation is that high poverty levels make it difficult for most rural communities to access modern farming techniques available on the market. This situation is worsened by relatively low literacy levels in the rural areas of Malawi, including Mzimba (75.3 %), Salima (56.9 %), Chikhwawa (53.1 %), and high HIV and AIDS prevalence rate of 9 % (NSO 2008, 2010). Generally, high levels of illiteracy and HIV and AIDS prevalence reduce the adaptive capacity of the local communities.

Climate Change Trends, Effects, and Adaptation Question in Malawi

Malawi is ranked as one of the twelve least developed countries most vulnerable to the adverse effects of climate change (World Bank 2010). This is so as the country's economy is heavily reliant on agricultural exports and subsistence farming, which are highly vulnerable to climate change. The country has a tropical continental climate characterized by wet/rainy and warm/dry seasons. The rainy season used to start in November and end in April, while dry season used to start in May and end in October. However, these seasons have not only become unpredictable but also display increased frequency and intensity of droughts and floods. Though it is difficult to predict long-term climate change scenarios, climate change pattern in Malawi mirrors climate change scenarios for Africa (Labaris 2012). Climate-related hazards such as prolonged dry spells, droughts, floods, and erratic rains have become more frequent, intense, and unpredictable. According to Oxfam (2009), Malawi's mean annual temperature has increased by 0.9 °C between 1960 and 2006, an average rate of 0.21 °C per decade. This figure is slightly higher than the global temperature increase of 0.18 °C per decade (AMCEN 2011). The average number of hot days per year has also increased by 30.5 between 1960 and 2003. The Global Climate Models project that mean annual temperature for Malawi is expected to increase by 1.0 °C to 3.0 °C by 2060 (World Bank 2011).

In the past 50 years, the country has experienced two major droughts in 1948/1949 and 1991/1992 and a number of floods related to cyclonic weather patterns in 1946, 1956, 1989, 1991, 1997, 2001, 2003, and early 2008. Prolonged periods of drought and floods were also registered between 2001 and 2005 (Action Aid 2012; UNDP 2007). According to Action Aid (2012), Malawi experienced 40 weather-related disasters between 1970 and 2006, but 16 of these occurred after 1990. In the south of the country, floods cause annual losses of about 12% of maize production, while drought destroys on average 4.6% of national maize production each year (World Bank 2011). Dry spells and heavy rains also resulted in an estimated 1.3 % economic growth slowed in 2010 (ADB 2011). Equally important, an increase in temperature has the potential to increase prevalence of malaria as its transmission and distribution is mainly determined by climatic conditions of temperature, humidity, and rainfall. In Malawi, malaria is an endemic public health problem and a leading cause of morbidity and mortality in children under age five and among pregnant women. It is estimated that Malawi experiences about six million episodes of malaria annually (GoM 2012a). All this shows that climate change and variability is real in Malawi. Despite these climate change and variability trends and effects, Malawi's contribution to global emission of green gases that are regarded as main drivers of climate change was estimated at only 29 M tons in 1990 (Mkwambisi and Gomani 2008).

Strategies of Climate Change Adaptation Employed in Malawi

Community adaptation to climate change is not a new phenomenon in Malawi. For several years local communities have protected and responded to periods of extreme climatic conditions by, inter alia, practicing crop diversification, informal irrigation, use of organic manure, mixed crop and animal farming, gathering edible fruits and tubers, and practicing seasonal migration from flood plains to upland areas (Kambewa 2005; Magombo et al. 2011). It should, however, be pointed out that autonomous adaptation to climate change and variability has become extremely costly and less rewarding to local communities over the years. Thus, planned adaptation, defined as anticipatory and government-undertaken or government-influenced adaptations, has become the option.

Malawi's climate change adaptation focus is primarily aimed at building the rural community's capacity to cope with changing climate change and making them resilient to extreme weather conditions. This focus is out of the realization that the country's economy is predominantly agro-based and 85% of its population depends on rain-fed farming for their livelihood. The agricultural sector contributes over 90 % to the country's export earnings, about 39 % of the country's gross domestic product (GDP), and accounts for 85 % of total employment (Chinsinga 2008; World Bank 2011). Over 84 % of Malawians eke their livelihoods directly out of rain-fed subsistence agriculture where women are responsible for a larger proportion of subsistence farming activities (Action Aid 2012). The effect of climate change in Malawi is aggravated by the country's heavy dependency on rain-fed farming and natural resources. It is estimated that 80 % of Malawi's food production and 65 % of the agricultural contribution to the country's GDP come from the smallholder farmers who predominantly depend on rain-fed farming (Chinsinga et al. 2012). Against this background, Malawi's National Adaptation Programmes of Action (NAPA) identified thirty-one adaptation options, and out of these options, fifteen were categorized as urgent. The following is a list of NAPA's fifteen urgent climate change adaptation options, which were further classified into high, medium, and low adaptation ranks as indicated:

- Sustaining life and livelihoods for the most vulnerable communities (high)
- Enhancing food security and developing community-based storage systems for seed and food (medium)
- Increasing crop production through the use of appropriate technologies (medium)
- Increasing resilience of food production systems to erratic rains by promoting production of maize and vegetables in dambos (river banks that have water throughout the year to support cultivation of arable crops), wetlands, and along rivers (high)
- Targeting afforestation and reafforestation programs to control siltation and provision of fuel wood for their benefits, such as sources of alternative cash income (high)

- Improving energy access and security in rural areas (e.g., through extension of rural electrification program, improved stoves, and development of ethanol-based stoves) (medium)
- Improving rural nutrition (e.g., through the promotion of fish farming, rearing of small stock, and nutritional supplements for children and the sick) (medium)
- Disseminating bed nets to high malaria incidence areas (medium)
- Developing food and water reserves for disaster preparedness and response (medium)
- Developing community-based wildlife ranching and a breeding program for Nyala (medium)
- Developing and implementing strategies for drought preparedness, flood zoning, and mitigation (medium)
- Developing technologies to mitigate climate change (medium)
- Providing standby power generation (low)
- Managing forest fires in collaboration with the community (low)
- Developing small dams and other storage facilities to mitigate flooding, to harvest water, and to initiate community fish farming and breeding (high)

Within these priorities, major community adaptation strategies to climate change practiced in Malawi include practicing conservation agriculture, growing drought-resistant and high-productivity varieties of seeds, practicing agroforestry and planting tree crops, and increased irrigation farming (GoM 2006; Chinsinga 2012). Conservation agriculture is a way of managing agroecosystems to achieve higher, sustained productivity, increased profits, and food security while enhancing the environment (Mkwambisi 2012). Specific strategies within this strategy include soil conservation agricultural practices such as terracing, crop rotation, intercropping, afforestation and reforestation, micro-irrigation, and natural resources management. The basic aim of conservation agriculture is to conserve soil condition that supports plant life by reducing soil erosion and runoff.

Growing of drought-tolerant and high-productivity crops involves use of improved seeds that mature early and are resistant to increased pests and diseases that are likely to accompany climate change (GoM 2006). Most smallholder farmers in Malawi have adopted these improved varieties through Fertilizer Input Subsidy Programme (FISP) in which poor farmers access inorganic fertilizer and seeds at a subsidized price. Agroforestry and planting tree crops involve planting of soil fertility-enhancing subsistence crops and cash crops such as *Jatropha*. Besides providing food and income, it is seen as a way of enhancing the livelihoods of farmers and mitigating the effects of climate change through carbon sequestration. However, there is reluctance of smallholder farmers to adopt agroforestry in Malawi because farmers do not see immediate benefits as trees take long to mature (Chinsinga et al. 2012). Decline per capital land size is another challenge facing agroforestry.

Prospects and Challenges of Community Adaptation to Climate Change in Malawi

Unclear Policy and Institutional Framework for Climate Change Adaptation

The Malawi government is a party to the United Nations Framework Convention on Climate Change having ratified it on 21 April 1994 as an operational tool for Agenda 21. However, apart from the 2006 NAPA document, the country does not have a coherent national policy framework on climate change. The National Climate Change Policy is still being drafted. The NAPA has identified thirty-three priority interventions across eight different sectors, and fifteen of these priorities aim at reducing the vulnerability of rural communities to climate change (GoM 2006). Climate change issues are also contained in a number of government policy documents such as Malawi Growth and Development Strategy II (2011–2016), National Environmental Policy (1996), National Environmental Action Plan (1996), National Land Policy (2002), Energy Policy (2003), Forestry Policy (1996), Fisheries Policy (2001), Water Policy (2005), National Irrigation Policy and Development Strategy (1998), and the National Biodiversity and Action Plan (2005).

However, these sectoral policy frameworks exist in isolation and are at times contradictory. For instance, while conservation agriculture is highly esteemed in climate change adaptation, its implementation has been placed at the periphery because it is not prioritized by the Ministry of Agriculture and Food Security. Driven by the primacy of food security in national politics, the government has increased nominal funding toward Fertilizer Input Subsidy Programme (FISP) since 2005/2006 growing season. Thus, climate change adaptation initiatives are caught in a political dilemma as legitimacy of the Malawian government is intimately connected to food security forcing the government to target achieving food security at all costs and placing other development priorities at the periphery (Chinsinga et al. 2012). For instance, in the 2013/2014 national budget, the government has allocated almost 50% of the Ministry of Agriculture's budget to FISP (US$187.2 million) and just over US$9.3 million to the Ministry of Environment and Climate Change (GoM 2013). This chapter, therefore, argues that sustainable community adaptation to climate is caught up in unclear policy environment. Currently, sustainable community adaptation to climate change is not a short-term objective of the government as it greatly wants to meet the immediate food security needs of the populace. Generally, climate change adaptation policies in developing countries are engineered toward meeting the immediate needs of a large proportion of poor people. In this process, it is not the government sustainable strategy that matters but the one that brings quick political rewards. Notwithstanding its positive contribution, the contribution of government-supported FISP through the subsidization of hybrid seeds and fertilizer to food security remains very debatable. For instance, when the subsidized farm input program collapsed in 1994, the share of land allocated to maize cultivation fell by 12 % (Action Aid 2006). This is so as most smallholder farmers cannot successfully grow hybrid maize as it is capital intensive.

Equally important, there is unclear institutional structure for managing climate change adaptation in Malawi. Currently, climate change issues are being handled by the Ministry of Environment and Climate Change, which was created in 2012. However, climate change adaptation issues are also implemented through a number of ministries and departments such as the Ministries of Agriculture and Food Security, Economic Planning, and Irrigation and Water Development. These ministries are, however, loosely coordinated resulting into duplication and at times conflicting policy objectives. This problem is aggravated by the ministries and departments' competition over the control of potential funding for climate change activities (Chinsinga et al. 2012). The lack of institutional coordination has resulted in local communities receiving contradictory messages from ministries and departments. For instance, while the Ministry of Agriculture and Food Security emphasizes the use of improved varieties of seeds in micro-irrigation projects, the Ministry of Environment and Climate Change prioritizes use of organic manure. Generally, the use of improved varieties of seeds is preferred with the objective of increasing national crop production and not really expanding local communities' livelihood platforms. The contentious issue concerning community adaptation to climate change, therefore, originates from policy stipulations of food security. In the present context, the government is significantly promoting maize production at the expense of other crops that favor specific agroecological regions. This direction mirrors the quantitative than the qualitative emphasis on community adaptation to climate change.

Local community adaptation to climate change in Malawi and many other developing countries in Africa has also to grasp with the recent government policy moves toward promotion of large-scale agriculture. Generally, policy moves toward large-scale farming are premised on two arguments, namely, the availability of large parcels of unutilized land and the contribution of large-scale agriculture to the welfare of local communities (Fisher et al. 2002). However, both justifications have been questioned by empirical experiences of large-scale investments in Malawi and other developing countries (Chinsinga et al. 2013). In the present context, large-scale agriculture is grabbing priceless land resource from local communities and makes them more vulnerable to economic shocks.

Inadequate Financial and Human Resources

One of the major challenges of local community adaptation to climate change in Malawi is limited financial and human capacity to implement adaptation programs. Generally, financial resources enhance adaptive capacity by enabling local communities to invest in environmental management and have freedom to choose appropriate climate change options. Human resource on the other hand affects the quality of implementation of adaptation strategies. Currently, Malawi will require

US$ 22.93 million to implement five identified priority areas concerned with community adaptation to climate change (GoM 2006). Most of this financial resource is assumed to come from the donor community, which hinges on the goodwill of the donor community. Thus, global climate change adaptation initiatives present development opportunities for local communities to access government and international funding toward climate change-related investment such as adoption of fast-maturing and drought-resistant varieties.

However, international financial support toward climate change adaptation has been far below expectations. The problem is that extreme poverty among most smallholder farmers in Malawi means that they can hardly meet the costs of improved seeds, fertilizer, and chemicals. Malawi is one of least developed countries with over 39 % of the country's population estimated living below the poverty line. Among rural households, the incidence of poverty is as high as 43 % (ADB 2012). The poverty situation in the country is also exacerbated by high population growth rates of about 2.8 %, which compounds the problem of pressure on agricultural land and forests. Discussions with local communities revealed that most farmers prefer local varieties because improved varieties of seeds are costly in terms of their price and inorganic fertilizers that they require. One bag of 50 kg inorganic fertilizer costs almost US$50, which translates to more than half of the rural population unable to buy a bag of fertilizer. According to one agricultural extension officer, "the main problem with use of improved varieties is that they require application of inorganic fertilizers and strict observations of modern farming methods." This requirement means a lot of people cannot manage to buy inorganic fertilizer (World Bank 2013). Ironically, current rainfall patterns make the growing of local varieties difficult. Equally important, while the Ministry of Agriculture prioritizes the scientific approach to adaptation, it does not have the needed human resource capacity in terms of agriculture extension workers to ensure that farmers are trained in the use of the scientific farming methods. Likewise, effective implementation of conservation agriculture demands the availability of adequate and well-trained labor force, something that is missing among rural farmers because of two conditions. Firstly, high HIV and AIDS prevalence of about 10.6 % (GoM 2012b) means that adults, especially women, spend a lot of time caring for the sick than concentrating on farming. For instance, three households reported during field interviews that they have not cultivated because they were caring for the sick during planting period. Secondly, low education levels among local communities make it very difficult for them to comprehend and adopt modern agricultural technology and practices. According to NSO (2010), 20.7 % and 13.0 % of rural women and men in Malawi, respectively, do not have any education.

Limited Information, Knowledge, and Technology on Climate Change

Community adaptation to climate change demands that communities should have and use adequate and correct information to estimate potential effects of climate change, map vulnerable communities, and design strategies to respond to climate change effects. Thus, predictions and availability of future climate change scenarios are an important step to community adaptation to climate change. One of the greatest constraints for local communities to adapt to climate change in Malawi is limited information on expected climatic patterns due to weak technical capacity to predict weather and climatic patterns. The result is that communities are not provided with adequate climate change and variation scenarios to base their adaptation decisions on. Farmers specifically are uncertain of when to plant. The failure of the country's Department of Meteorology to provide comprehensive and long-term data on climate change and changing weather patterns does not only constrain policy making regarding climate change but is also a major source of anxiety among farmers as it increases their losses and vulnerability to climate change. According to one government official report:

> We (government) do not have adequate capacity in terms of structures like data storage capacity and computers, and we lack required expertise in some areas. We also have a general shortage of staff. Lack of a Meteorological Act also affects our work because now we use the Civil Aviation Act. The draft of the Meteorological Act had to be withdrawn from Cabinet because it did not include climate change issues. (AFIDEP, 2012:27)

Lack of required technology by the Department of Meteorology means that there is inadequate up-to-date data to guide community adaptation to climate change in Malawi. This challenge is worsened by the fact that climate change research is mainly done on a global level and there is little contextualization of global data at national and subnational levels. In most developing countries such as Malawi, reversing this trend will not be achieved in the near future due to inadequate government funding channeled to capacity development of institutions dealing with issues of climate change. In general, there is overdependence on donors for funding of climate change work (Chinsinga 2012; UN OHRLLS 2009). Given the increasing social and economic needs of the population in developing countries, it is doubtful that the state will allocate adequate resources to long-term climate adaptation needs such as recruiting adequate staff dealing with climate change and buying modern equipments for climate prediction. For instance, the Department of Meteorology is operating with less than half required human capacity. Thus, donor support will for a time remain the country's sure hope of accessing modern technology in climate change human capacity development. This hope is, however, grossly threatened by the general failure of developed countries to honor their climate change adaptation promises to developing countries. According to the IIED (2011), developed countries have made little progress toward their overall fast-start adaptation target currently pegged at 19–25 % of total fast-start finance.

Currently, there is a lot of confusion about the best strategy to climate change adaptation among the local communities and even among the educated group. For instance, over half of interviewed academicians outside the agriculture specialization argued that most modern farming techniques such as use of chemicals are not good as they reduce soil fertility. According to one academician who usually designs farmers' radio programs, chemicals require following strict procedures as they may make the soil completely unproductive. Another academician interviewed reported that his relatives refused to use improved varieties and chemicals in their farm because they do not trust modern seeds and chemical. They argued that "these seeds will make us poor because we cannot use them again next year, what are we going to do if we fail to find money to buy new seeds." These sentiments were also common among local farmers, which show that there is a lot of mistrust toward new farming technologies. Thus, the battle for local community adaptation to climate change will be easy unless farmers have adequate information on the subject.

Social Infrastructure and Equity

Successful community adaptation to climate change requires that local resources be equitably allocated and distributed among local community members. Equitable allocation of resources within the community largely depends on the extent to which individuals are able to participate in adaptation activities without social, economic, or political barriers. This is one of the challenges facing local communities in the effort to adapt to climate change in Malawi. Generally, there are three main climate change adaptation strategies being practiced in Malawi, namely, conservation agriculture, use of drought-resistant seed varieties, and agroforestry. The Least Developed Countries Fund (LDCF), for instance, funded Malawi US$3 million to implement rural livelihood and agriculture which largely included use of improved crop seeds, improved crop sequencing, and irrigation. However, such strategies have the potential of increasing income inequality among local communities by favoring the haves in society. The benefits of improved crop sequencing are premised on growing of two crops in one growing season through following strict growing calendars. Lessons from many irrigation initiatives in the country such as Mpemba irrigation scheme in Ntcheu, however, reveal that crop sequencing may not be a panacea for climate change adaptation to the powerless and landless groups of people in a community. This is so as land parcels belonging to individual households are compulsorily subdivided to willing households during dry season, thereby creating two land right arrangements, namely, individual land user rights during rainy season and collective land user rights during dry season. The expectation is that two strict crop-growing seasons are going to be followed and that crops for each growing season are going to mature strictly within the specified growing season.

However, this assumption may not be the case with increasing unpredictable rainfall pattern in the area (see UNDP 2007). Again, the designed strict growing arrangement restricts the types of crops grown during rain-fed and dry season as crops have different maturing periods. Some crops such as maize mature within 4 months, while some crops mature late but are also consumed for a long time while in the field. According to the interviews conducted with the communities in the area, only maize and vegetables are allowed to be grown under this arrangement and crops which are grown late into rainy season and mature late such as sweet potatoes are not allowed. The problem is that some of the crops not allowed to be grown under this arrangement form a major part of the local community food nutrient. This situation calls into question the extent to which local people will benefit from the climate change adaptation strategies. As earlier explained, crops grown in the irrigation scheme are preferred with the objective of increasing national crop production and not really expanding local livelihood platforms. The contentious issue concerning community adaptation to climate change, therefore, originates from the capitalistic conceptualization of food security. In the context of Malawi, increased production has emphasized the quantitative aspect and disregarded the qualitative aspects of diversified livelihood. Analysis of climate change adaptation debate supports this trend by emphasizing increased production of crops widely involved in market economy at the expense of local crops which form a major part of local livelihoods.

Conclusion

Community adaptation to climate change in developing countries is vital, taking into account the negative effects of climatic change. There is widespread agreement that external assistance is necessary if this process is to be achieved. To this end, there is generally real and expected global assistance toward climate change adaptation. However, analysis of local community adaptation to climate in Malawi has revealed that communities face a number of challenges to adapt. Firstly, there is no clear policy and institutional framework guiding climate change adaptation initiatives. Secondly, local communities lack the necessary monetary resources to effectively engage in adaptation initiatives. In particular, high poverty and illiteracy levels make it difficult for the communities to adopt new farming technologies. These observations suggest one critical point to consider; although climate change adaptation is a sure way of escaping negative effects of climate change, its success heavily depends on a number of development-related variables. Thus, arising from this observation, climate change is unlikely to be successful if it is implemented in isolation of other economic development variables especially poverty, literacy, and governance.

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Responding to Climate Change: Ecological Modernization in Bangladesh's Agriculture

Saleh Ahmed

Contents

Abstract

Climate change is one of the biggest humanitarian challenges in many parts of the world. Unfortunately, low-income developing countries in the Global South will be the major victims, even though they are not the major driver of this global environmental change. It is not very uncommon that the people, community, and the country in the Global South are putting efforts to develop their own resiliency strategies to confront this challenge. With a regional focus on southwest Bangladesh, which is one of the major climate hot spots in the world, this chapter tries to explain climate resilient efforts particularly in agriculture sector with a lens of ecological modernization theory. The findings of this chapter highlight the importance of understanding ecological modernization as well as required process and mechanisms for climate resilient agriculture practice. Even though

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the findings are theoretically grounded, the focus is on how the theory can be translated with further modifications, if necessary, into local communities. It is expected that this chapter will have larger implications by generating further theoretical and empirical discourse focusing on low-income developing countries in the Global South.

Keywords

Bangladesh • Climate change adaptation • Climate change • Ecological modernization theory

Background

Changing climate and associated impacts are among the major humanitarian crises of our contemporary society. It can obviously make changes to our economy, society, politics, and environment at large. It will have influence on our food supply and the patterns of livelihoods. However, the impacts of changing global environment will not be homogenous. People in the low-income developing nations will face larger exposure and vulnerability. Even though in most cases poor people are not the major driving forces for environmental or climate change, unfortunately they will be the major victims of this changing environment.

Climate policy, or more generally nation's environmental policy, is increasingly intertwined with the logic of ecological modernization (Curran 2009). While in Bangladesh the term "ecological modernization" is not officially adopted or widely used, the nation's climate policy or climate adaptation debate increasingly takes place within the larger domain of ecological modernization. In the present context of climate vulnerability and risks, the logics and promises of ecological modernization have never been so compelling. Like many other social sciences theories, this is also not an exception from criticisms and proposals for refinements.

This particular chapter reviews the perspectives of ecological modernization with a regional focus on southwest Bangladesh. Climate resilient agriculture is at the core of this discussion. As the major share of population are predominantly engaged in agriculture-related activities, changing pattern of agriculture has large implications on society and economy. Bangladesh is one of the most densely populated and poorest countries in the world (Streatfield and Karar 2008; Clayton 2013). One in every three Bangladeshis is poor and the ratio is slightly more in the rural areas (Clayton 2013). Despite huge population and pervasive poverty, the country has demonstrated progressive trajectories towards growth and development, based on a number of development indicators, such as the Human Development Index (BBS 2007). On the contrary, the global environmental change, e.g., climate change, can jeopardize the country's current trend with social and economic progresses.

It is one of the most vulnerable countries due to extreme climate events. Low-lying topography of the southwest coastal landforms of Bangladesh suggests that minimal increase in sea level can have catastrophic impacts on the coastal communities and the country at large (Abedin and Shaw 2013). One meter rise in sea level can be the reason for landlessness of 14.8 million people. That can also make 40 million people internally displaced due to the loss of 29,846 km^2 of land area in largely coastal areas (Brown 2011). The majority of the affected people will be poor that are dependent on local and regional natural resources such as fisheries, forestry, agriculture, etc.

In this changing situations of climate, agriculture, the major economic base in the country, can be affected severely followed by damages to many other livelihood opportunities (Brown 2011; Madhu and Jahid 2010). In Bangladesh, agriculture is a climate-sensitive sector. It is dependent on seasonal weather variability (Abedin and Shaw 2013). Due to the changing pattern of climate, rice production in Bangladesh is predicted to fall by 8 % and wheat production by 32 % until 2050 (Climate Change Cell 2009).

Southwest Bangladesh is often treated as the most disaster-prone region in the country due to its exposure to extreme climate events in coastal areas, such as salinity intrusion, increased intensity and frequency of tropical cyclones, tidal surges, floods, repeated water logging, etc. Approximately ten million people live in this region. Apart from this, the region is treated as one of the poorest regions in the country. Often the regional poverty dynamics is shaped by the ecological conditions and entitlements. The Sundarbans, world's largest mangrove forest, is one of the major suppliers of livelihood opportunities to majority of the coastal population, illustrating people's interactions and dependencies on nature and natural resource as a whole (Pravda Bangladesh 2009). Extreme climate events will eventually have adverse impacts on this regional resource base and at the end will disrupt this coupled human and natural system in local and regional scale.

To confront climate challenge, now Bangladesh is also focusing on climate resilient agriculture to feed its burgeoning population. Often this comes with different forms of ecological modernization such as agriculture intensification. The available lands for agriculture are not abundant in Bangladesh. This illustrates that there are not many options available for horizontal expansion of agriculture; rather vertical expansion is often treated as the most affordable option. Vertical expansion of agriculture, a form of intensification, can be perceived within the larger framework of ecological modernization. Bangladesh is a cosigner country with the Kyoto protocol along with other major environmental treaties, and therefore, the country is legally bonded for its improvements towards ecological efficiency.

In a low-income developing country like Bangladesh, there usually exists a huge vacuum to conceptualize the ecological modernization theory with implications. People often strive for sustainability without any substantial theoretical focus. As a consequence, society experiences the malpractices and implications of innovations and technological advancement. The theoretical development of ecological modernization was largely taken in the western European countries. Till to date, there is little to no research discussing the Global South and its connection to climate change adaptation mechanisms.

This chapter is an attempt to contribute to the discourse of ecological modernization focusing on the Global South, where the majority of the world population resides. This chapter discusses how climate resilient agriculture can be discussed within the larger framework of ecological modernization theory in the context of southwest Bangladesh. Even though the findings in this chapter are largely theoretically grounded, however, it is intended to focus on how the theory can be translated with further modifications, where necessary, into local communities of the Global South.

Local Environmental Challenges

Bangladesh is often characterized by her yearly monsoon patterns. Therefore, in Bangladesh, agriculture is largely treated as a weather-sensitive sector. Even though local agriculture is heavily dependent on monsoon rains, excessive monsoon rains can cause substantial crop damages. Therefore, delay of plantation and damage of produced crops are among the most significant losses due to the unpredictable pattern of monsoon rains. Often it creates massive flash floods. The flood in 1988 caused the reduction of agriculture production by forty-five percent. In a resource-constrained country like Bangladesh, it was a big national security challenge. The country became heavily dependent on food exports and aid for meeting the local consumption demands. However, flood in this extent is not rare in Bangladesh. In the recent years, the frequency and the extent of floods have substantially increased (Fig. 1).

Apart from floods, tropical cyclones and storm surges can also make damages to agriculture. The Cyclone Sidr struck the coastal Bangladesh on November 15, 2007. The total damage of crops was approximately Bangladesh Taka 28.4 billion (76 BDT = 1 US$), and the total loss of production in all crops was 1.3 million metric tons (Madhu and Jahid 2010). Natural hazards like floods, droughts, cyclones, etc. are likely to increase in frequency and in intensity due to the changing nature of climate (Abedin and Shaw 2013; IPCC 2007), and it is not a surprise that these disasters will generate further challenges for agriculture in Bangladesh (Abedin and Shaw 2013). Salinity intrusion is another major environmental challenge in the region. If it generates regional humanitarian crisis due to the lack of drinkable water and cultivable land, then southwest coastal Bangladesh will be treated as one of the major climate hot spots in human history. A migration from coastal Bangladesh to other parts of the country is already an increasing phenomenon. Lack of drinking water and salinity intrusion in land and water are shaping this migration dynamics. This process with salinity intrusion can be further increased by the reduced dry-season freshwater supply from upstream sources resulting from climate change (IPCC 1998) as well as by the increasing salinity intrusion due to sea-level rise (Abedin and Shaw 2013). These mentioned environmental challenges, heightened mostly due to climate change, will gradually contribute to the fact of decreasing amount of available agriculture lands.

In addition to that, population growth and unplanned and uncontrolled urbanization also contribute to the declining trends with prime agriculture land.

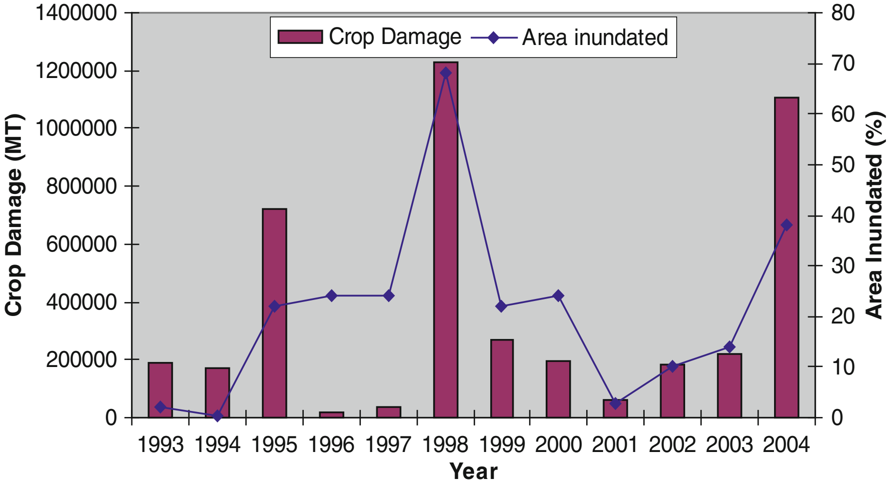

Fig. 1 Crop damage (in metric ton) due to historical flood (Source: Madhu and Jahid 2010)

Right now the declining rate of agriculture land is approximately 1 % per annum (Ahmed 2010). The land use change from farm to nonfarm activities is another phenomenon in this land-constrained country. The loss of agricultural lands and the adverse impacts on overall agriculture warn us about the possible future food shortage for the country's growing population. An emerging middle-class population will likely consume more and that will eventually increase the demand for consumption in the entire country. The conflict or mismatch between demand and supply of agriculture products will most likely increase the country's vulnerability to further social, economic, and political chaos (Fig. 2).

The national picture of agriculture challenges is not very different in southwest coastal Bangladesh. The region is the home of 35.1 million people (Bangladesh Bureau of Statistics 2011). The majority of populations are poor, mostly marginalized farmers and fishermen, or dependent on other natural resources. The net cultivable lands are 1.95 million hectares. This average landholding per household is half of national average (Abedin and Shaw 2013).

Possible Solution: Climate Resilient Agriculture

As the climate change is not any more a theoretical or abstract concept, rather very much visible in regional context, the southwest Bangladesh is in urgency to focus on different climate resilient agricultural practices (Mahmood 2006). However, evidence shows that in the southwest coastal areas, the evaluation and demonstration of climate resilient high-yielding rice varieties have been neglected until recently (Clayton 2013). Fewer farmers adopted the modern agricultural practices and mostly remained lock with traditional agriculture practice (Clayton 2013).

Fig. 2 Southwest coastal area of Bangladesh (Source: CoastalCare 2011)

It is important to reinforce that climate resilient agriculture practice will reduce substantially the risks and vulnerabilities associated with climate change (Abedin and Shaw 2013) and that is particularly relevant and have larger implications in the low-income developing countries where the adaptive capacities are extremely limited. Climate resilient agriculture can contribute to four strategic objectives: it can contribute to ensure the production of adequate food for the bourgeoning population; alleviation of poverty particularly among the poor and marginalized farmers can be promoted; access to food will help to achieve better health and nutrition; and finally, it contribute to conserve the local natural resource base, which is not only helpful for the environment, but can also contribute to the local productivity, economy, and long-term sustainability (CGIAR 2011).

Even though the climate resilient agriculture has a paramount importance, the implications of modernization and associated consequences are not very clear to the local policy makers and also to the farmers. This makes the situation complicated, because without understanding the process of (ecological) modernization, the local society might end up by generating further negative impacts on nature, such as loss of biodiversity.

Business-as-usual can no longer any effective mechanism to understand the context and challenges. Innovative concepts and practices are required therefore for a region’s sustainability. Evidence shows in the southwest coastal regions, improving water efficiency and crop diversification should be at the core of local adaptation efforts (Abedin and Shaw 2013; Fig. 3).

Apart from environmental dimension, climate resilient agriculture has social dimensions. In some situations, it is primarily driven by social forces like local consumption pattern or profit-oriented production systems. Changing agricultural

Fig. 3 Floating agriculture practice (Source: Rahman 2013)

pattern can alter this conventional trajectory. The entire process of climate resilient agriculture should be conceived as a coupled interaction between human and nature. One-dimensional approach of climate resiliency can disrupt the entire systems of sustainability. Agricultural modernization (or ecological modernization) largely depends on how the people can link their eco-efficiency of production system with the market force. It is not an easy process; rather it involves farmers' awareness and engagement with climate resilient farming practice along with the state and policy supports for coupled understanding of modernization and long-term impacts.

Theoretical Framework: Ecological Modernization

Core Arguments

Joseph Huber was among the first group of ecological modernization theorists who put substantial importance on the role of technological innovations in environmental reform. Even though the theory of ecological modernization presents a complex array and understanding of postindustrial modern society, however, the core argument involves contemporary technological innovation. Therefore, the proponents of ecological modernization see continued industrial development as the best possible option for escaping from the advanced societies' ecological crises (Fisher and Freudenburg 2001).

Ecological modernization can be one of the major reference points in contemporary social sciences disciplines for analyzing society-environment interactions (Mol and Sonnenfeld 2000). A large share of ecological modernization literature has been developed by the sociologists, and therefore, the theory or the perspective has become influential within the subdiscipline of environmental sociology (Buttel 2000).

Initially ecological modernization perspective emerged as the hegemonic environmental discourse focusing on the advanced developed societies. Gradually, it shows its prospective neoliberal solution to the global environmental crisis, such as climate change (Lippert 2010). The core argument of the ecological modernization is to reach a balanced and synergistic relationship between industrialized societies and their environment. Therefore, these developed societies need to engage with nature more techno-scientifically efforts. At the same time, the market economy should mediate the process (Lippert 2010). In summary, the core arguments of ecological modernization could be as follows:

> An ecological modernization perspective hypothesizes that while the most challenging environmental problems of this century and the next have (or will have) been caused by modernization and industrialization, their solutions must necessary lie in more – rather than less – modernization and 'superindustrialization.' (Buttel 2000, p. 61)

The logic of ecological modernization entails a postmodernist perspective. The ideological development surrounded on the perceived inadequacy of neo-Marxist interpretation schemes. Ecological modernization perspective challenges the core ideas of de-modernization (Mol and Spaargaren 2000). The core of ecological modernization illustrates that increasing industrialization can solve contemporary environmental problems. An ecologically modernized society should adopt the core principles of environmentalism in the design of locally available institutions to regulate human interactions with nature (Mol and Spaargaren 2005). Therefore, a vibrant local market economy and democratically elected government, along with constitutionally guaranteed rights and freedoms, are basic prerequisites for realizing ecological modernization. It is clearly evident that ecological modernization theorists highlight the process of structural change in economic, political, and cultural institutions that can directly influence the environmental outcomes. These propositions are closely aligned with the contemporary sustainable development agenda and initiatives where substantial importance on institutions and institutional capacity is clearly evident (Mol and Spaargaren 2005). Proponents of ecological modernization believe that currently we are exposed to ecological modernization and, to tackle global environmental challenge, we need more modernized efforts in terms of eco-efficiency (Lippert 2010). So far the empirical evidences of ecological modernization are largely from advanced industrial societies. One of the major reasons is that ecological modernization requires advanced technological development, a state regulated economy, and widespread environmental consciousness and behavior for the desired green industrial restructuring.

Criticisms

The logic of ecological modernization is not beyond criticisms. It argues that eco-efficiency can be achieved without radical structural changes in state and civil society (Buttel 2000). A majority of criticisms are surrounding to this argument. Therefore, if we really need to understand the theoretical arguments of ecological modernization and its implications on some specific geographical context, it is also important to discuss the counterarguments of ecological modernization.

Firstly, the perspectives of ecological modernization differ from neo-Marxist social theories in paying little attention to changing relations of production or to altering the capitalist mode of production altogether. Therefore, ecological modernization perspective misses the point, how modernization exploits labor and resource base for the sake of increasing profits. In addition to that, the proponents of ecological modernization also believe that some institutions and/or organizations will become more "ecologically rational" at the later stages of development or modernization. However, developing countries might respond to this differently. Even though at the later stage of modernization it can be ecologically rational, that process of development already can make substantial damages of resource base with the exploitation of labor and production interaction, where the working class usually get exploited by the capital class. This process of development can actually generate increasing phenomenon with the treadmill of production. Apart from that, evidence shows that ecological modernization efforts were mostly successful to produce solutions to "conventional" environmental problems such as surface water pollution and solid waste management; however, high-consequence risks like climate change can only be explained with more rational integration of social and natural systems.

Neo-Marxist perspective also criticizes ecological modernization because it overlooks the effect of modernization by additions to and withdrawals from nature (Schnaiberg 1980). For example, modern production systems require greater material inputs, e.g., fertilizers. It is capital intensive, and hence, more energy is needed to run the system. It is intended to increase the production levels, thus requiring far more raw materials. Usually agricultural intensification (modernization) can lead substantial chemical additions to the nature. It can generate environmental problems, such as natural resource depletion and pollution of land and water. This can adversely impact the land's productive capacity.

From the very beginning the major critique of ecological modernization theory is the technological optimism as well as perceived technocratic character (Mol and Spaargaren 2000). It is mostly based on the invention, innovation, and diffusion of newer technologies and associated techniques of operating industrial processes (Murphy 2000). This is clearly evident that ecological modernization advocates for super-industrialization. It will generate substantial pressure on economy, nature, and society, and at the same time, not all developing countries in the Global South can follow this modernistic trajectory with ecological modernization due to its own social, economic, and political situations. Without having some levels of economic efficiency, it is very hard to generate and/or promote ecological modernization. It can generate extra burden to the economy as well as to the society. More elaborately, even if the low-income developing countries follow the trajectory with ecological modernization, it will be interesting to explore at what cost and what would be the implications for labor and production relationship. Will the modernization generate profits for the large corporates or continue to marginalize the working class people? Still the proponents of ecological modernization are not very clear on these questions focusing on Global South.

If we summarize the major critics of ecological modernization, we can see that there is no compelling evidence available from where see can see that the ecological sphere has been detached from the economic sphere in decision-making criteria. In addition to that, ecological modernization has focused narrowly on ecological issues by neglecting or overlooking other equally important components of social processes, such as social equity (Pellow et al. 2000).

Without considering these challenges, modernization can generate even further pollution by increasing environmental and economic loads to the working class people, who will be the major victims of adverse impacts of changing climate. Apart from that, in many of the developing countries, the quality of governance and political and social institutions is very weak to support the country's endeavor towards ecological modernization. It is a concern that might derail the ecological modernization efforts in low-income developing countries.

Perspectives on Bangladesh

In Bangladesh, ecological modernization is at the very early stage of conceptualization and implementation. The process is going through restructuring in the local sociopolitical context and challenges. Not only in developing countries like in Bangladesh but also in developed societies it is not very uncommon that agricultural modernization or intensification as part of ecological modernization without proper supervision can cause the loss of fertility of prime agriculture lands. By modernizing agriculture sector in Bangladesh, there is a big chance that the farmers will not be the ultimate beneficiary groups. Big corporates might consume the major share of profits. Apart from that, as the ecological modernization process is technology driven, it might disrupt the local community structure and practice.

Therefore, it is a critical issue for Bangladesh how the country can follow the trajectory of growth and modernization within the larger framework of ecological modernization. Even though the agricultural vulnerability is high and adaptation needs are paramount, very little efforts have made so far to understand the potentials of agricultural adaptation (Abedin and Shaw 2013) and more particularly from the theoretical point of view.

Since the very beginning of ecological modernization discourse, scholars identified two distinct patterns within this framework: weak ecological modernization and strong ecological modernization (developed by Christoff 1996, but also discussed in Blowers 1997; Mol 2001; Dryzek et al. 2002). Weak ecological modernization can be characterized for its sole focus on efficiency and technological solutions by promoting technocratic and corporatist patterns of decision-making. It is treated as an initiative to introduce a single, focused, nondemocratic, and closed-ended framework and initiatives on political and economic structures and development.

The core ideology of weak ecological modernization is to maintain both the political legitimacy and market competitiveness, because the state and market emphasize on environmental benefits through technological advancements (Schlosberg and Rinfret 2008). However, this narrowly defined ecological modernization reflects no significant changes to corporate or political structures and often provides minimal ecological outcomes (Christoff 1996). However in contrast, a stronger ecological modernization considers broad ranging changes to the society's institutional structures and economic systems (Schlosberg and Rinfret 2008). The process often involves open democratic decision-making by using precautionary principles of modernization, and in addition to that it involves opportunities for political development (Schlosberg and Rinfret 2008).

Within the discourse of ecological modernization, we can see that even if Bangladesh adopt ecological modernization perspective, the process entails the components of weak ecological modernization, because its framework narrowly focuses on how alternative technological advancement can enhance the agriculture productivity as well as local economy. This narrowly focused conceptualization of ecological modernization does not involve opportunities for broader societal change in response to changing climate. The current trajectory of ecological modernization in Bangladesh clearly misses the opportunity for conceptualizing the situation from a holistic perspective, and it argues on more importance for broader change with enhanced democratic governance on crucial issues (Schlosberg and Rinfret 2008).

Summary

Agriculture is the major defining factor for food security and social development in Bangladesh. The associated problems of agriculture are multifaceted. Therefore, responding to climate change is complex and interdependent. The local society needs to understand the coupled relationships of human and natural systems prior to any specific modernization efforts.

Ecological modernization is a relatively new concept, and in many ways it is an improved perspective towards sustainable development. It is obviously an attractive concept of modernization, because it provides us an alternative to the pessimistic connotations of development frameworks such as the treadmill of production and growth machine (Buttel 2000).

Considering the local economy, society and political structure ensuring "strong" ecological modernization is a challenging task in Bangladesh. It is important to mention that ecological modernization is not necessarily a uniform prescription for all sectors. It can work better in some particular sectors than others. Advanced developed countries with mature governance are in advantageous position for ensuring ecological modernization. Low-income developing countries have contrasting scenarios.

In Bangladesh, climate adaptation strategy particularly the climate resilient agriculture practice is very much aligned with the concept of "weak" ecological modernization.

To avoid further distress, it would be important for the local society to focus more on the "community-based" side of the process; that means, the process should be led by the local community. The technocratic approach of ecological modernization can generate further disarray in the system and society.

In general, the farmers of the southwest Bangladesh are now interested on innovation and adaptation of climate resilient agriculture practice, such as floating-bed cultivation system. It is a good sign for eco-efficiency responding to climate change. However, it is important to mention that to speedup the process, the market and state should continue further research and development on new varieties of saline- and flood-tolerant crops and strive to disseminate new information and skills among the farmers and local community to create locally conducive environment and precondition for "strong" ecological modernization in southwest Bangladesh.

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Security Implication of Climate Change Between Farmers and Cattle Rearers in Northern Nigeria: A Case Study of Three Communities in Kura Local Government of Kano State

Salisu Lawal Halliru

Contents

Abstract

This study focused on the implication of climate change between cattle rearers and farmers in the desert-prone line in northern Nigeria which led to unavoidable crisis and insecurity in Nigeria and Africa in general. The consequence of climate change has untold security implications on the life of Nigerians; attacks in the country have been traced to the doorsteps of two strange groups that are forced to live together as a result of unfavorable climatic conditions in the Northern part of the country. The conflict between Fulani and farming communities linked to disputes over grazing land has become frequent in parts of central and northern Nigeria in recent years. The method of purposive random sampling was employed to select the local government and communities where data was

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collected for this study. The measures for selecting the communities include the following: community with a sizable number of cattle rearers with at least ten (10) heads of cattle and above, community with more than one communal clash which involves the farmers and the Fulani, community with both permanent cattle rearers' settlement and transit Fulani that are always on the move, and agricultural economy-based community. Interviews were also conducted, and 60 respondents were purposively selected: fifteen (15) Fulani, six (6) traditional rulers, and 39 farmers. A qualitative method of data collection was used to gather information, and in-depth interviews were chosen as an appropriate data collection tool; the interview was drafted in Fulfulde language and was later translated into English and the Hausa language was translated into English as well. Multiple data were collected from February to April 2010 and July to September 2010. The study revealed population increase also takes over grazing land as a result of development, paths of animals (Burtali) in the past are now taken over by farmers, desert encroachment has taken over vast farmland, and the quest for a greener pasture usually brings the Fulani crisis among others. These researches also join others before it to call for more research on climate change and insecurity in Africa generally. Finally, this paper recommended ways on how to address immense challenges of adaptation, through educating farmers and the Fulani on the implication of climate change, and reduce human activities which further aggravate and cause climate change – planting of Jatropha plants to prevent animals from going into farms to destroy crops and creating grazing land.

Keywords
Climate change • Security • Fulani • Farmers • Conflicts

Introduction

A clash over land ownership and grazing land for animals has continued to grow in the few years. The growing pressure for land these past few years has been described by many experts and onlookers as a clear manifestation of the impact of climate change across Nigeria with most states in the far North being the worst affected by these changes. Security has been a major issue in Nigeria's development crisis. Climate change is one of such problems that are globally identified but the effects of which are more pronounced in developing countries. Recurrent droughts, in conjunction with other social and economic factors, have led to conflicts among farmers and cattle rearers. These conflicts are a constant threat to the security of those in the community affected.

Sudano-Sahelian zones of northern Nigeria have suffered environmental degradation caused by successive years of poor rainfall and recurrent droughts, exacerbated by the combined effects of natural population growth and in-migration with the growing population; more land is being cultivated and less is available for pasture and traditional land use systems that rely on mobility. As average rainfall decreases, pastoralists have migrated south into land occupied by sedentary farmers

Fig 1 Map of Nigeria

(Nyong 2009). It is predicted that the majority of Nigerian and all African countries inclusive will have novel climates over at least half of their current crop year by 2050 (IPCC 2007). Already climate change rate is gradually exceeding the adaptive capacity of a broad range of crop and forage varieties, animal breeds, and tree populations in Nigeria, ten years earlier than the IPCC climate model prediction of 2020 (IPCC 2007).

The descriptions of the climate of Nigeria and northwest Nigeria have been rather simplistic due to paucity of data, but with the availability of data manipulation techniques, it is possible to discuss more fundamental features of the climate. Such is necessary at this point in time as recent droughts, water shortages, and fauna and flora depletion have highlighted how important it is to understand weather phenomena (Oguntoyimbo, 1982 in Obioha 2005) and how they affect human security. Nigeria is one of the countries in the West African subregion; it has an estimated population of 140,003,542 people (NPC 2006) spread over a land area of 932,768 km^2 (Fig. 1).

Disasters such as cyclone Nargis and the China earthquake claimed thousands of lives, ruined millions of livelihoods, and caused billions of pounds worth of damage. Disasters have always been with us, but they are becoming more frequent and more severe. As global warming increases the frequency and severity of climate extremes, there are more weather-related disasters. It can leave people without access to food and water, without incomes as crops fail, and displaced from home by flooding or drought (DFID 2009).

Climate changes have forced some cattle rearers (Fulani) to leave their region and migrate to the southwest where the effects of climate change have not been so severe. If the harmattan is not well pronounced in a particular month/season, the hot condition often takes over, creating a strong heat stress in the atmosphere. The stress so created is highest in the region of convergence between the two air masses often referred to as ITD (Inter Tropical Discontinuenity) – the zone of meeting between the dry northeast harmattan wind and wet southwest wind (Michael 2010).

The intercommunal crises have been traced to the aftermath of the effects of climate change in Nigeria. People that have been affected by the consequences of climate change move to other communities where the effects of climate change are less severe or that have not experienced disaster occasioned by the effects of climate change. The rate at which intercommunal clashes occur between the Fulani herdsmen and their host communities is recurrent event in Nigeria. Most of these crises have been traced to pressure on land and destruction of farmland by the Fulani herdsmen during cattle grazing (Michael 2010).

Aim and Objective

The main aim of the study is to examine the security implication of climate change between farmers and cattle rearers that led to communal conflicts in Kura, Kano state (Fig. 2). From which the following objectives were derived:

1. To examine the communal conflicts resulting from climate change and agriculture
2. To observe the physical exposure and the immense challenges of adaptation in northern Nigeria where the study area falls
3. To highlight the potential impacts of climate change on security and the strategies for addressing these challenges

Statement of the Research Problem

Conflicts between cattle rearers and farming communities linked to disputes over grazing land have become frequent in parts of central and northern Nigeria in recent years. Some analysts have blamed the trend on increasing desertification which is pushing cattle rearers southward in their search for pasture, often putting them in conflict with farmers (Olabode and Ajibade 2010). In view of the above, there is a serious need to answer the regular question "what have been the causes of the conflict?" so that we can draw a line and come up with a solution.

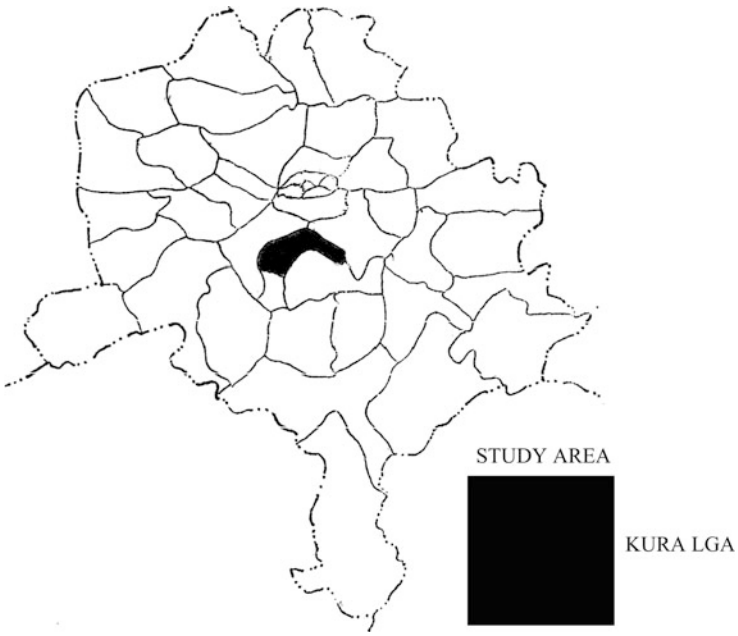

Fig 2 Map of Kano state showing the study area

Justification and Importance of the Study

In the world, generally, conflicts have led to grave consequences like starvation, death, social unrest, poverty, and unquantifiable losses among the citizens of different nations. There is therefore a need to study and understand the causes and processes of conflict and find appropriate strategies for addressing these challenges. The intensity of the conflict between cattle rearers known as BAKWALOGI or BORO, herdsmen with red cows and sheep migrating from Niger every year to enter Kano state, where the study location is, call for timely mitigation and adaptation measures of reducing the frequent conflict occurrence that displaces local farmers and claims lives and crops as well.

Study Area

This study was carried out in Kura local government area of Kano state, Nigeria. The area was selected because agriculture is the bedrock of its economy and it has been victim of the Bakwalogi–farmer conflict for a long time. The study area is located at the southern part of Kano state with a population of 144,601 million people (NPC 2006) with a land mass of 206 km^2, located between 11° 46′12.84″N and

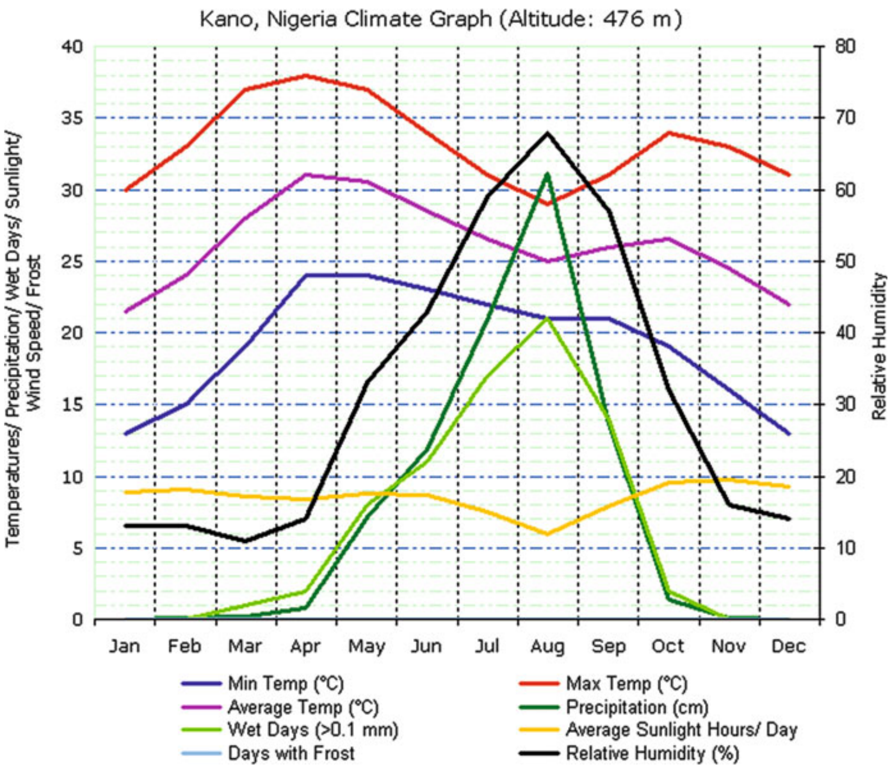

Fig 3 Climate of Kano state (Source: Field study 2010)

longitude 8°35′29.02″E; it is about 900 km from the edge of the Sahara desert and 1,140 km away from the Atlantic Ocean approximately.

The study area shares a boundary in the north and the east with Kumbotso local government; west to south, it boarders with Madobi and Garun Malan local government areas, respectively, and extreme south to east, it boarders with Bunkure local government area (Fig. 2). The area has three marked temperature regimes (warm, hot, and cold) with mean annual temperature of 26°C and 21°C main monthly range of maximum temperature in December/January and over 35°C which is hottest (April/May); wet season starts in May and ends in October, while November to February is a dry cool season with harmattan haze. Vegetation is savanna (grassland) of Sahel–Sudan Guinea type (Salisu 2009; Fig. 3).

Methodology

Three communities were selected from this local government; purposive random sampling was employed to select the local government and communities where data was collected for this study. Three communities were chosen to represent

Table 1 Totality of the respondents

S/no	Respondent	Number
1	Cattle rearers	15
2	Traditional rulers	06
3	Farmers	39
Total	Respondent	60

Source: Field study 2010

the local government purposively selected. The measures for selecting the communities include the following:

1. Community with a sizable number of cattle rearers with at least ten (10) heads of cattle
2. Community with more than one communal clash which involves the farmers and cattle rearers
3. Community with permanent cattle rearers' settlement and transit Fulani that are always on the move
4. Agricultural economy-based community

On the above criteria, Karfi, Dukawa, and rigar-gundutse were selected as the study location. Sixty respondents were also purposively selected (twenty from each community). The following distribution of respondents was obtained: cattle rearers (5), traditional rulers (2), and farmers (13) from each of the three communities selected for this study (Table 1).

A qualitative method of data collection was used to gather information from the respondents, because majority of the respondents are not formally educated and cannot fill in questionnaires adequately. In-depth interviews were chosen as an appropriate data collection tool. The interview guide was wholly structured but also contained open-ended questions to allow a free-flow discussion and unedited information from respondents.

The cattle rearers' interview was drafted in *Fulfulde*; the data collected was later translated into English for the purpose of analysis. Also, the traditional rulers' and farmers' interviews were prepared in Hausa language for data collection. The data collected was also translated into English language for data interpretation.

Data Collection

Multiple data were collected over six months, three months during the dry season (February to April 2010) and the three months during the rainy season (July to September 2010). Data were collected during the dry season since this is the critical period when there is no pasture for grazing and farmers are busy during irrigation activities.

Findings and Discussion

The study revealed that in the past, people were very few and there was enough land for grazing, but now the population has increased so there are fewer lands to farm on. Desert encroachment has not eaten deeper to the southern Kano. Cattle rearers are nomads who move from one location to another to find pasture for their cattle. Changing climate forces them to move where they can get a greener pasture, water, and a friendly environment for their cattle and families. Variability in climate has altered the environment with unbearable effects which are significant in severe desert encroachment, drought, etc.

The place with high cattle population lament for the highest cases of conflict between cattle rearers and farmers due to limited dry season grazing resources (Table 2).

Another observable and major thing that brings clashes between the ***Fulani*** and farmers in the study area is paths for animals in the past (Burtali) are now taken over by the farmers and other developments; hence, the paths are taken over in the process of searching their way to available grazing land and they end up destroying crops in the farmland that is why there are always clashes between the cattle herders and farmers.

The cattle come in droves, invading most farmlands in search of better grazing land as desert encroachment seems to have taken over vast farmlands in the far north, while the farmers who are already feeling the impact of the changes, especially delayed and interrupted rainfall, are protesting the invasion of their farms by the cattle rearers.

The above are conflicts where actors rationally calculated their interest in a zero-sum or negative-sum situation such as might arise from resource scarcity. Table 3 shows that there is a positive feedback relationship between the northwest as it is in the northeastern Nigeria and quest by competing interests to control the available scarce resource in the area (Obioha 2005). The need for more food has led to a serious conflict over land. Violent conflicts involving different typologies that were identified in the study area are very recurrent. Another agent of conflict which we identified arises from large-scale movements of (Bakwalogi/Baroroji) Fulani herdsmen from neighboring countries (Niger and Chad axis) as a result of environmental change.

Security Implications of Violent Conflict

Human security involves the protection of individuals from a sudden violent attack on one person or property, the security being described as having two principal aspects: the freedom from chronic threats such as hunger, disease, and repression, coupled with the protection from sudden calamities, and a number of significant harms that go unmitigated. The seven components of human security are economic, food, health, environmental, personal, community, and political security (United Nations Development Programme 1994). In a more analytically useful manner, Owens (2004) and Obioha (2005) defined human security as protection of

Table 2 Observed number of cows kept by cattle rearers

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rigar-gundutse	200	20	50	30	150	100	30	300	50	150	100	30	40	50
Dukawa	250	200	300	200	200	200	150	50	80	60	150	150	60	20
Karfi	100	60	100	200	50	150	70	100	100	30	30	20	100	80
Total	550	280	450	430	400	450	250	450	280	240	280	200	100	150

Source: Field study (2010)

Table 3 Typologies of climatically induced violent conflict over land resources in northeast Nigeria

Types	Level	Actors	Occupation	Stake	Dimension	Objective sort
TP1	Interethnic	Indigene/ settler	Cultivators/ herdsmen	Vegetation and land	Domestic/ international	Relief from scarcity/ reinforcement of group identity
TP2	Interethnic	Indigene/ settler	Cultivator/ cultivators	Arable land	Domestic	Relief from scarcity/ reinforcement of group identity
TP3	Interethnic	Indigene/ settler	Herdsmen/ herdsmen	Grazing land	Domestic/ international	Relief from scarcity/ reinforcement of group identity
TP4	Interethnic	Indigene/ settler	Cultivator/ cultivators	Arable land	Domestic	Relief from scarcity/ reinforcement of group identity
TP5	Interethnic	Indigene/ indigene	Cultivator/ cultivators	Arable land	Domestic	Distributive justice
TP6	Interethnic	Indigene/ indigene	Herdsmen/ herdsmen	Grazing land	Domestic	Relief from scarcity
TP7	Interethnic	Settler/ settler	Herdsmen/ herdsmen	Grazing land	Domestic	Relief from scarcity
TP8	Interethnic	Settler/ settler	Cultivator/ cultivators	Arable land	Domestic	Distributive justice
TP9	Interpersonal	Settler/ settler	Cultivator/ cultivators	Arable land	Domestic	Distributive justice
TP10	Interpersonal	Settler/ indigene	Cultivator/ cultivators	Arable land	Domestic	Distributive justice
TP11	Interpersonal	Indigene/ indigene	Cultivator/ cultivators	Arable land	Domestic	Distributive justice

Source: Adopted after Obioha 2005, classifications of conflict in North East Nigeria

the “vital core” of all human lives from “critical and pervasive” environmental, economic, food, health, and personal threats due to climate change. A drop in agricultural output may weaken rural communities.

Identified Security Implication at the Study Area

- Decreased agricultural production
- Hunger, disease, and malnutrition
- Destruction of farmland/farm crops
- Killing of livestock owned by the herdsmen
- Economic decline
- Population displacement
- Fighting between cattle rearers and farmers which results in loss of lives and injuries every year

Table 4 Factors that attract the cattle rearers

Push factors	Pull factors
Drought and desert storm	Green vegetation
Poor weather condition	Moderate weather
Strange diseases	Hope and aspiration
No water for animals	Market opportunity
Lake Chad is dried up	Forage

Source: Field study 2010

The consequence of climate change has untold security implications on the life of Nigerians. A series of interethnic, interreligious, and reprisal attacks in the country have been traced to the doorsteps of two strange groups that are forced to live together as a result of unfavorable climatic conditions in the northern part of the country (Adediran 2010; Table 4).

The above are pushes and pull factors that attracted the cattle rearers which eventually led to unavoidable crisis, conflict, and insecurity. The following are the extracts from the interview conducted with the cattle rearers and farmers in the three communities selected for this study:

> We travel from far away to find grass for our cows to feed on and how ever we get a Small area to graze on, the farmers come and tell us to go away, where do they want Us to go and feed our cows. (Musa/cattle rearer)

> We travel to far away state close to the border of Niger Republic to feed our cows but Now the weather has changed and the place is full of dry ground and sand which why We came here as we used to do before but now we are always fighting with the Farmers

> Before we can feed our animals we are not allowed to let our animals drink even water In the river. (Bello/cattle rearer)

> Farm lands are no longer as fertile as they use to be in the past so it is really painful For farmers to struggle and spend so much money buying fertilizer and then watch As cattle herders drive their animals to feed on the crops. (Yawale/farmer)

> It is difficult to avoid confrontation with cattle rearers these days because more of them are coming into our farms more especially in the night to destroyed our crops their animals and runaway. (Abdulmumini/farmer)

Conclusion

The devastating impact of climate change is expected to force more people into the north central except if mitigation and adaptation strategies are put in place immediately; most farmers interviewed in Kura local government were not aware of the impacts of climate change, but they said they noticed the gradual changes in the weather and the environment but are not aware of what is causing the changes.

The quests for greener pasture by the (Fulani) herdsmen usually bring them in contact with farmers involved in crop production. In most cases, this contact results to invasion of the cropland of the farmers by the livestock of the migratory group. Conflicts that usually arise in this process are usually violent and long lasting, which may have some internal repercussion around neighboring states and borders.

From all observations, the human security implication of the conflict is enormous, because other areas of human needs are usually in danger wherever there is conflict. This study also found that climate change has and still is affecting farmers and the people in northern Nigeria economically, socially, and otherwise.

Recommendation

- People must be educated on the need to reduce human activities such as tree felling, burning of carbon fuel and biomass, as well as gas flaring which further aggravate and cause climate change.
- Farmers are to demarcate areas of the farms by planting Jatropha plants around it to prevent animals from going into the farms to destroy crops. Animals do not feed on Jatropha nor do they go near the plant because it emits an odor that repels animals.
- Reforestation in the drought-prone areas of northern Nigeria needs to be boosted.
- Nigeria as a country should invest more in combating climate change; agricultural and climatological research should be enhanced to combat desert encroachment.
- Creation of grazing land in each state, local government and communities with standard ranching method that can bring reduction of seasonal in- regional movement of the Fulani, periodic orientation for the Fulani at the grazing point, viable economic value both on the animals and herdsmen.

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Social Capital and Local Institutions: A Perspective to Assess Communities Adaptation Potential to Climate Change

Bhaskar Padigala

Contents

Abstract

Communities residing in Himalayan mountain environment are particularly at risk to climate changes externalities owing to their high dependence on natural resources, relatively high contact to severe climatic events, and prevalent economic and infrastructural marginalization. The present article tries to explore the nature of local society-environment interactions, particularly the role of social institutions and social capital in adaptive capacity to possible climate change impacts in Miyar watershed situated in the northeastern part of Lahaul and Spiti district of Himachal Pradesh, India. The first part of the article deals with climate change perception among local communities and the following part deals with identification and evaluation of adaptive capacities and prevailing institutional mechanisms.

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Study findings indicate that local community in Miyar valley, over the time, has developed variety of efficient resource (natural and human) management strategies and institutions (like *Jowari* system and *Kuhl* Committee, etc.) formed as a result of social cohesiveness (social capital), collective action, and common motivation to deal with both environmental and nonenvironmental changes. These aspects of local institutions and social capital are directly related to resource management and community development, but it also provides a buffer zone for the communities to adapt against any future changes (climatic variability, social or economic, etc.) up to some extent.

Keywords
Climate change • Social capital • Adaptation • Local institutions • Collective action

Introduction

Vast amount of scientific literature suggests that the climate is gradually altering and that anthropogenic activities like GHG emissions and ecosystem degradation have resulted in accelerating these climatic variability's and its associated disastrous impacts (Aizebeokhai 2009; Hansen et al. 2000). Alarming projections by IPCC 2001 indicate that the global temperature is on rising trend, and by the end of twenty-first century and depending on the emissions, these raise in the global mean temperatures likely varies anything between 1.4 °C and 5.8 °C (Lal 2002).

These increases in climate variability are likely to have wide range of impacts, ranging from sea level rise (Hallegatte et al. 2011; Galbraith et al. 2002), forest degradation (Watson 2000), glaciers melting (Barnett et al. 2005; Singh and Kumar 1997), and many more (Parmesan and Yohe 2003; Thomas et al. 2004; Watson et al. 1998). Even though, the probability, intensity, and geographical distribution of these impacts are still a lot unclear (Schneider 2001). But, the fact remains that despite the type and location of these impacts, marginalized communities (both economically and socially) are likely to be the most vulnerable sections in the society (Furgal and Seguin 2006; Raleigh 2010; Downing 2003).

Similarly, communities inhabiting Himalayan mountain ecosystem are likely to be more vulnerable and impacted to climate variability owning to fragile environment, lack of proper infrastructure, livelihood instability, and their high dependence on local natural resources (Macchi 2011). But, care must be taken not to attribute all these impacts to environmental and climatic availabilities, since communities and their interactions are very complex and there are many other factors or drivers that also influence communities' actions and responses like social, political, and economic factors.

Mountain communities have always been at risk due to limited natural resources and fragile ecosystem they live in, but at the same time, these communities have also developed a great potential resilience to these limitations by incorporating interventions at different scale like traditional land and water management practices

(Gadgil et al. 2003; Friedman and Rangan 1993; Padigala 2013), village institutions and resource governance (Agrawal 2001; Ostrom 2005), etc. Still, very limited studies have been carried out to understand impacts of climate variability on Himalayan communities and their resilience capacities to the same (Eriksson et al. 2009; Ensor and Berger 2009). Thus, it is imperative to understand these local adaptive capacities and assess their potential for climate change.

Understanding Human Adaptive Potential and Social Capital

Wide-ranging discussions revolving around the topic of climate variability deal with vulnerability and impacts on the natural ecosystem and especially on human systems (Smith et al. 2000). As a consequence, assessment of community vulnerability and its adaptation capacity is garnering rising interest among wide range of stakeholders like grassroot organizations, policymakers, researchers, etc. (Burton et al. 2005; Thomas and Twyman 2005; Moser and Ekstrom 2010). However, measuring adaptation capacities is difficult to ascertain, as it involves predicting the adaptive capacity for potential crisis periods. Even more, the adaptive capacity to climate variability is also influenced by other dependent aspects like social, political, economic, technological, and institutional factors, thus making assessment of adaptation potential all the way more uncertain (Van Aalst et al. 2008).

Throughout the literature many researchers through their research have tried to define a complex aspect, i.e., adaptive capacity (Folke et al. 2002; Grothmann and Patt 2005). Brooks (2003) in his work define adaptive capacity as “reductions in social vulnerability as arising from the realization of adaptive capacity as adaptation. The term adaptation means adjustments in a system’s behaviour and characteristics that enhance its ability to cope with external stresses.” This hereby means that, a system over the time will cultivate capacity of adaptation to reduce its vulnerability with consistent levels of risks. Adaptive capacity is many times used as an indicator for climate change adaption potential of a society (Grothmann and Patt 2005; Adger and Vincent 2005; Adger 2003; Kelly and Adger 2000). However, it is important to understand that this potential is based on various interconnected asset bases like financial capital, human capital, social capital, etc. Thus, cumulative vulnerability and adaptive capacity of a society can be estimated by understanding resource management strategies and these assets.

The one element which is common to all the five forms of capital is that there is a stock associated with each capital, which can be channelized into a flow of benefits. The stock of financial capital, for example, is associated with a flow of benefit, which is the interest. Similarly, social capital is associated with a benefit which has been termed as “Mutually Beneficial Collective Action” or MBCA (Krishna and Uphoff 2002).

Adaptive capacity is a multivariate idea, not only it is interconnected with different assets but this interrelationship also runs across different scales. At the national level, adaptive capacity is represented by the accessibility of financial resources and institutional and governance capability for resource management thereby reducing the vulnerability of marginalized sections of the society. At the household level, this capacity is more dependent on the livelihood and knowledge base of the individual. Thus, assessing adaptive capacity based on different assets and across different scales is very important for building up successful adaption model for future climatic as well as non-climatic variability's (Vincent 2007). Thus, it is therefore very difficult to create a universal set of indicators to determine adaptive capacity hence these indicators need to be devised and modified suiting to individual cases (Adger et al. 2004).

Speaking of adaption strategies and models, their success largely depends on the identification of the indicators or assets and also on the willingness of the vulnerable community. Thus, adaptive potential of a community primarily depends upon local institutions, governance aspects, and the social capital.

Communities have innate capability to acclimatize to environmental variability's. These capacities are outcome of society's capability to work cooperatively. These choices of adaptation strategies are taken by institutions formed by individuals from within the community. Hence, one of the key elements of this article has been to explore the nature of these society-environment interactions, particularly the role of social institutions and social capital in adaptation processes and capacity.

Social capital and its role in adaptation have been getting lot of interest among researchers and practitioners alike (Pretty 2003; Katz 2000; Pretty and Ward 2001; Adger 2003; Pretty and Smith 2004; Adger 2001). Social capital can be understood as a system of networks, concurrence, and information flow that is integrated into the fabric of society. The scope of the concept of social capital varies considerably in the literature. Putnam provides a more narrow theory of social capital. According to Putnam (1993), social capital can be viewed as *a set of* "horizontal associations" *between people: social capital consists of social networks* ("networks of civic engagement") *and associated norms that have an effect on the productivity of the community*. Defining social capital in two-way process, Coleman (1988) defines it as a network of vertical and horizontal associations, wherein social capital encompasses both the positive and negative aspects of the associations. Lastly, defining it in more border sense, North (1990) suggests that social capital embraces the social and political situations and transforms the social arrangements and interactions thereby helping the society to develop. Adger (1999, 2000) in his studies has indicated economic and political processes in Vietnam that have led to reviving of resilience of informal networks against the risks of sea-flooding. This argument directly indicates the role of institutions and networks among the society and its significance in economic and social development.

It should be understood that social capital is a system of institutions governing a society, but it is also an aspect that encompasses relations and interactions among the individuals which are facilitated and governed by institutions, norms, values, and extent of the capital (economic, human, and natural) commanded by these connected individuals.

Social capital is more than a theoretical notion, and it does provide variety of social benefits like increased collective actions among individuals (Knack and Keefer 1997) and efficient functioning of local governmental and civic institutions (Bebbington 1997). But, understanding and measuring social capital is fraught with uncertainties and probabilities. However, over the years many researchers across the globe have attempted to understand this aspect, in rural Tanzania (Narayan and Pritchett 1999) using Social Capital and Poverty Survey (SCPS) found that at village level, increasing income levels have direct correlation with the extent of social capital. Similarly, Knack and Keefer (1997) in their research used the indicators of trust and civic norms to understand the correlation between economic development and social capital.

Traditional notion of community development is based on the four capitals or assets, i.e., financial, natural, physical, and human capitals, but with predicated impacts due to climatic variability and urgent need for inclusive sustainable development, it is imperative that the social capital needs to be also brought into the mainstream planning and decision making (Grootaert 1998). Since, social capital is the crucial link that governs the nature and extent of interactions between different societal entities to generate growth and development.

Local Institutions and Climate Adaptation

As discussed in previous sections, communities have inherent capacity to reduce vulnerability to climatic variability owning to many adaptation strategies developed over the time. But the effectiveness of these adaptations largely depends on the structure and operation of the institutions. According to Agarwal (2010) these institutions can be classified into three categories, namely, (1) public or state (local agencies & local governments), (2) private or market (service organizations & private businesses), and (3) civic (membership organizations, cooperatives). And these organizations through its range of activities like capacity building, resource mobilization, information channelling, etc., reduce the community's vulnerability and increases resilience.

Undeniably, the role of institutions at multiple scales, including household level, has been identified; Eakin (2005) in his study across three communities in Mexico observed that resource management strategies applied in these communities are largely successful due to presence of local institutions. Similarly in Trinidad and Tobago, formation of informal institution has led to successful coastal management thereby highlighting the role of local institutions, social capital, and information flow in natural resource management (Tompkins and Adger 2004). Related studies on various themes like water conservation (Padigala 2013; Mosse 1995; Cleaver 1998), agricultural management (Uphoff 1992; Little and Brokensha 1987), pastoral management (Niamir-Fuller 2005), and forest governance (Gibson et al. 2000; Hayes 2006) have all indicated the significant role of institutions in the management of resources. But relatively limited studies have been carried out to assess the institutions role in climate change adaptation (Naess et al. 2005; Berkes and Jolly 2002), especially in Himalayan ecosystem.

From the above discourse it is evident that local institutions are vital component in community's resilience and adaptation to climate change. However, there is still information gap on measuring the effectiveness of these local institutions and social capital against climate change impacts and ways to mainstream these "bottom up" aspects in the traditional climate change adaptation planning and decision-making process, which follow a "top-to-bottom" approach. The following section would shed light on these very issues of community-based natural resource management strategies and social capital and role local institutions in Miyar valley and asses effectiveness of these interventions against likely climate change impacts on the communities.

Introduction to Miyar Valley

The Miyar watershed lies in the northeastern part of Lahaul and Spiti district of Himachal Pradesh extending between 32°42′36″ N – 33°15′24″N – 33°15′24″N latitude to 76°40′12″E – 77°1′15″ E longitude (Fig. 1). The community living in the area is exclusively dependent on the climate, natural resources, and social collective action for their survival. The study area included five villages (Tingrit, Ghumpa, Urgos, Sukto, and Khanjar) (Table 1) which were taken to learn the socioeconomic aspects, land use dynamics, and community adaptive capacity of the area. The site was selected considering the two circumstances (viz., climate dependency and changing economic pattern) and how these situations and community will behave in the light of current global environmental change.

The main livelihood source in the valley is agriculture; being a rain shadow area, the only source of irrigation water is snow meltwater along with some amount of glacial water. Also the area receives heavy snowfall during winters from October to March causing complete halt to agricultural activities and hindrance to the normal life; this means that people get only the remaining six months to do agriculture and gather food and fodder for themselves and for their livestocks.

From the last few years, the area is witnessing change in the economic and land use pattern due to the introduction of cash crops like peas, seed potato, etc., which has lead to increased economic stability in community and also change in the land use of the area like conversion of small patches of forest and grazing lands into agricultural fields by villagers.

However, Sen et al. (2011) indicate that the major recent economic transformation in Miyar valley has been diversification of traditional agricultural practice towards cash crops like peas, which is a perishable commodity. The possibility of better income thus is connected to transportation of the commodity to the market in time. Thus, road or transport seems to be the single major reason for diversification. Majority of small farmers report higher income as the driving force; a large section of larger farmers feel that the road is what makes commercialization possible. The major conclusion that comes out from this study is that the recent changes in the valley cannot be directly related to climate change only.

Though there is a lack of benchmark data, there is no doubt that the current trend of commercialization has uplifted the livelihood status of the valley which has been primarily driven by increased connectivity of sthe region. Thus, it becomes important to inquire as to whether the community sees commercialization as a risky proposition and, subsequently, to identify the major risk variables (climatic as well as non-climatic) as perceived by the communities.

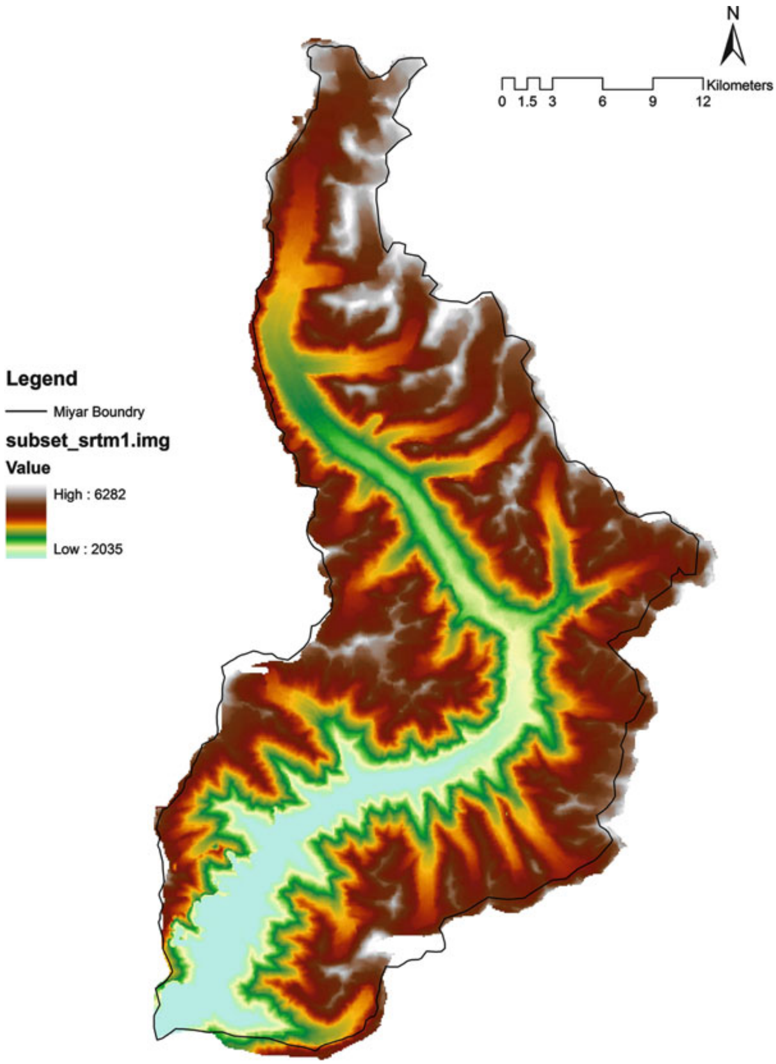

Fig. 1 Figure showing a digital elevation model of Miyar valley

Methodology

In this study the adaptive capacity of the communities were assessed using the model of sustainable livelihoods approach (SLA). The SLA was employed to create an understanding of the livelihood patterns among the inhabitants, since the livelihood assets are important parameters to assess the vulnerability and capacity of the communities to adapt against environmental and socioeconomic changes.

Table 1 Showing population growth in the area

Village	Total population 1999		Total population 2001		Total population 2010	
	Male	Female	Male	Female	Male	Female
Khanjar	25	26	29	32	25	23
Sukto	Data not available				20	17
Urgos	Data not available				114	112
Ghumpa	Data not available				21	24
Tingrit	154	123	167	144	93	78

Source: District Census Handbook 1991, 2001, Lahaul & Spiti, Registrar General and Census Commissioner, Ministry of Home Affairs, Govt. of India

Livelihood can be defined as "the capabilities, assets (including both material and social resources), and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base" (DFID 1999).

Being geographically located in fragile and extreme ecosystem, these communities have already developed livelihood assets to adapt to environmental and socioeconomic changes. Thus, sustainable livelihoods approach (SLA) also provides crucial impetus on strongly and weakly developed assets in the community. This in turn is crucial to strengthen these weakly developed assets, so as to increase community's adaptive capacity.

The sustainable livelihoods approach (SLA) exhibits the primary issues that have impact on people's livelihoods and their different assets. SLA categorizes these assets into five types: human capital, financial capital, physical asset, environmental capital, and lastly, social capital (Fig. 2). Table 2 shows the various proxy indicators used during the study to assess the adaptive capacity of the communities inhabiting Miyar valley.

Study involved the collection of primary data (field verification and mapping, household surveys with sample size of 80 households out of 120 houses in the selected five villages) from the field. This primary data was supported by a wide-ranging study and examination of secondary literature and other region specific documents like census data, topographic sheets and satellite data, and climatic data of the study area.

Primary data from the study area was collected according to the community-based vulnerability and capacity assessment approach (CBVCA) framework. This framework was modified to suit the site conditions.

In a community-based vulnerability and capacity assessment approach (CBVCA), primary informations are collected using different quantitative and qualitative research techniques including focus group discussions (FGDs), key informant interviews and participatory rural appraisal (PRA) methods at the community and household levels. While conducting the evaluation to the household residents and the community members or the representatives of different institutions, it was made sure that the idea "climate change" and its aspects and impacts were not directly incorporated or mentioned. This was done so as to forbid any predisposition in their answers.

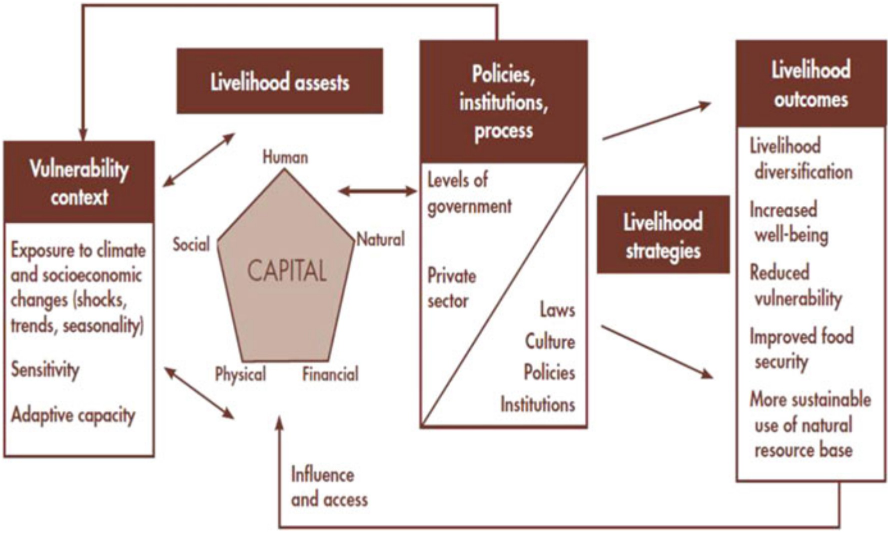

Fig. 2 Figure showing sustainable livelihoods framework (Source Macchi 2011)

Table 2 Showing sectors/capacities and proxy indicators applied to measure adaptive capacity of community for the study

Adaptive capacity	
Sectors/resources	Proxy indicators
Human capital	Family size, education, knowledge, and skills
Financial capital	Income sources, savings, credits and loans
Physical capital	House structure and materials, road connectivity, local technologies and equipments
Environment (resources) capital	Natural resources (pasture land, forest, fresh water resources), land holding per family
Social capital	Social structure and relationships, local governance, community support, trust, bonding, and network

Principally, apart from collecting primary data, to gather data on community-based VCAs, qualitative research methods were undertaken since qualitative research techniques provides an achievable scenario to study the history of that community and its different crucial aspects like gender, culture, ethnicity, etc. These factors are essential in observing and understanding the source reasons for social and economic susceptibility to transformations, environmental, as well as other aspects (Birkmann and Wisner 2006).

Statistical Package for Social Science (SPSS) and Excel computer software were used to analyze the collected quantitative data. From a researcher's perspective, it was taken care that there are also other factors or drivers of change in the Miyar valley like infrastructure development, change in land use, agricultural patterns, and outmigration, etc., apart from climate change, thereby not attributing every change (both externalities as well as opportunities) to climate change. Furthermore, to validate the collected data, during the study the communities' perception on climate change aspects were authenticated using information gathered from secondary literature and sources. This was done so that the conclusions coming out from this study were realistic and in turn facilitates future policy and developmental interventions that ensures enhanced resilience of the communities.

Results and Discussions

Environmental Change Perception

Miyar region is heavily dependent on the temperature variability and water availability, because the main source of livelihood for the community in the area is agriculture. With increasing temperature the cropping season might increase, and also the availability of irrigation water will fluctuate. A variety of literature on climatic variability and climatic modelling on Himalayan region suggests an increasing trend in temperature in the near future (Bhutiyani et al. 2007; Ageta and Kadota 1992; IPCC 2007).

More than 65 % of the respondents from across the villages perceived that there has been change in the temperature of the valley and the change has been on the higher side, i.e., villagers felt that the temperature has increased a little since the past 10–30 years. Along with temperature respondents also perceived a slight increase in the duration of the summer season (Table 3).

Correlating to the temperature change, villagers were asked about change in the agriculture practices due to increased duration of the summer season, and it was found that more than 90 % farmers from all villages (up to 100 % in Sukto and Tingrit) have not increased the cropping numbers. Likewise, 100 % of the respondents from all villages replied that they have not adapted to any new variety of crop. However, respondents do feel that the cropping season has extended a little.

It was very interesting to know that, despite perceiving increase in temperature and extension in the cropping season, farmers were not taking advantage of it. This could be attributed to two reasons: first that though there seem to be some change in temperature but the change is small and not that significant to which they should adapt in agricultural practices and secondly, farmers experienced that the annual snowfall is increasing and its season is getting erratic, due to which there is a great risk if people try to harvest a second crop. Since the first crop harvesting lasts up to October the month for potatoes and August the month for peas, if they try to harvest the second crop after the peas, the crop will require 2–3 months time before it could yield and thus the harvesting time overlaps with the commencement of the winter season with snowfall that could pose a huge threat to standing crop if the snowfall occurs little early that year.

With rain almost unknown and erratic, the amount and availability of the irrigation water greatly depends on the yearly snowfall. For the year with scanty

Table 3 Respondents perception to changes

	Parameters											
	Change in temperature		Change in cropping number		Change in cropping type		Change in cropping time		Change in snowfall		Change in drinking water availability	
	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)
Village												
Thingrit	80.0	20.0	0	100.0	0	100	15.0	85.0	55.0	45.0	10.0	90.0
Ghumpa	70.0	30.0	10.0	90.0	0	100	40.0	60.0	60.0	40.0	10.0	90.0
Urgos	84.8	15.2	6.1	93.9	0	100	18.2	81.8	72.7	27.3	15.2	84.8
Sukto	66.7	33.3	0	100.0	0	100	16.7	83.3	50.0	50.0	16.7	83.3
Khanjar	72.7	27.3	9.1	90.9	0	100	9.1	90.9	45.5	54.5	18.2	81.8

snowfall, streams dwindle quickly and dry up in the beginning of August and hence crops suffer. Thus, during this study it became important to understand the observation of the community with respect to snowfall variability in the area.

During the survey it was found out that all villages expect village Khanjar to display above 50 % agreement to the phenomenon of increased snowfall in the area. Villagers also feel that duration of onset and the season of snowfall have reduced slightly. Moreover when inquired about water-related hazards to the area such as cloud burst-induced floods or GLOFs (glacial lake outburst floods), villagers felt positive risk about it, though the occurrence of the floods in the area has been very sporadic, like the only recent case of flood was back in year 2000, where only one small village (Changut) was partially affected by the flood.

One of the most observable changes of global warming in the Himalayan region is the withdrawal of the glaciers, at advanced rates than glaciers in other regions (Pathak 2010). This continued deglaciation could have an intense impact on the hydrology and water flows in the river basins starting off in the NW Himalayan region (Rao et al. 2008; Jianchu et al. 2009). Owing to this increased speed of glacier melting, water discharges in the glacial-fed rivers are more expected to rise for some time, before decreasing as the ice storage of the glaciers gradually decreases (Karki et al. 2009).

With several literature predicting scarcity of drinking water in it was surprising to find that majority of the local community did not recognize any change in the drinking water availability (more than 80 % respondents across all villages). The major source for drinking water for the village in the study area is spring water; occasionally following the year with less snowfall few spring sources got dried up. To which villagers have no problem in adjusting and finding a new source for water supply.

But these predicted changes in water regime due to likely future environmental variability will no doubt change and up to some extent disturb the local economy and natural resource availability and accessibility. It can also be believed that these changes will certainly transform the functioning of local institutions and governance along with social capital and communal actions in the region.

Local Adaptations and Institutions for Resource Management

From the above sections it is evident that climatic variability has been also perceived by the locals, yet they do not feel any risk associated with it (Table 4). Following section tries to explore what are the different resources available to the community, what strategies are being employed to manage these resources for their development, and whether these adaptive mechanisms can be seen as indicators for adaptive potential to climate change.

The valley has almost unrestrained source of water supply for both irrigation and drinking purposes. The majority of the villages which lie on the plateaux on both sides of the main river get water from the streams which trickle down from the cliffs (Saini 2008). The amount and availability of the irrigation water greatly depends on

Table 4 Coping and adaptation mechanisms implemented by the communities

S. No.	Parameter	Communities perception of change	Impact on livelihood	Communities perception of risk to change	Coping and adaptation
1.	Temperature change	Slight increase	No significant impact	No risk	No coping and adaptation
2.	Snowfall	Increased	Little impact	No risk (risk is there if, they try to take two crops in a season)	No coping and adaptation
3.	Drinking water availability	No significant change		No risk (risk is there if, following year after less snowfall spring dries up)	Diversion of the spring water system to the new source

the yearly snowfall and glacier meltwater. Drinking water is obtained from the springs. The gravity-type water supply schemes have been installed in every village to provide drinking water.

Vegetation cover of the Miyar watershed is of central Asian or Siberia type with dry alpine character at lower elevation. Low precipitation is another reason for scanty vegetation in the area. Vegetation distribution of the region has been divided into three zones. First zone extends from 2,590 to 3,350 m.s.l and contains maximum vegetation with nearly all the trees that exist in the watershed, viz., juniper, blue pine; and birch. Second region ranges from 3,350 to 4,875 m.s.l where most characteristic plant *Rheum moorcroftiana* is which does not thrive below that height.

Total number of species recorded from the study area is 142, from which 17 are trees, 18 shrubs, 85 herbs, and 22 lichens. *Asteraceae* and *Fabaceae* are the dominant family in the area with 15 and 12 species, respectively. In trees *Salicaceae* and *Pinaceae* are represented by 5 and 4 species, respectively; *Asteraceae* and *Fabaceae* are also dominant families in the herbaceous layer (Forest Working Plan 1996–2006).

Quite a few patches of juniper tree (*Juniperus semiglobosa*) can be seen here, which represents subalpine forests in the region. This is one of the featured species of high conservation and religious importance in the valley.

Glaciers are devoid of any vegetation while a narrow belt below glacier contains lichen, mosses, and few other grasses. The forest patches are very sparse and were depleting before 1980 because forest wood was the only material available for house construction and fuel wood. This led to rapid reduction in forest area; to this with this situation *Mahila Mandal* was formed and it has proven successful in its mission.

Miyar valley is also endowed with large areas of grasslands with nutritive grasses (*Poa* sp and *Agropyron* sp) which attract many heads of sheep and goats with transhumance.

The valley due to its climatic and geographical condition and various other reasons lacks the luxury of abundance of natural resource (except for water resource), and also the valley people cannot undertake large scale developmental interventions because of various constraints like only limited season to grow crops, loss of physical contact with the outer world during winters due to avalanches and road blockages, etc.

But people in the Miyar valley, over the ages, have adapted to manage and sustainably utilize resources like forest resources, pasture, water resources, manpower, etc., for their development. Mentioned below are the few fine examples of the collective action, awareness, resilience, and excellent social bonding to adapt community against resource scarcity and to attain overall community development.

Jowari: Labor Exchange (Resource Management)

One of the best examples of efficient resource management and collective community action is reciprocal labor exchanges in agriculture. There is no class of landless agricultural labors in the villages; even the poorest owns a small patch.

The short season between snowfalls for cultivation creates an immense time constraint on production along with shortage of casual labors (usually Nepali migrants). People have adapted to this by pooling their labor. A labor pool will usually include 4–5 families who share manpower, bullocks, and plow; weed; and harvest the fields in rotation. Generally women are the ones who work in labor exchange (Fig. 3).

Community Livestock Grazing

Due to short season of summer season, farmers have to deal with maintaining duel economic task of farming and livestock rearing to keep their financial condition stabilized. Now due to greater financial gains, villagers are more involved in farming and hence they have adopted an innovative way to tackle the problem of livestock rearing by practicing community livestock grazing.

Fig. 3 *Jowari*: Labor Exchange (Resource Management)

Each village has extensive private irrigated grasslands, usually on slopes which are too steep for cultivation or on large bunds between fields. These areas are opened as commons to the cattle in April and closed when the fields are put under cultivation. The livestock are then taken to alpine pastures by a grazier who receives payment from all households in the village (e.g., village Tingrit has employed two grazier for a sum of INR 50,000 to look after village livestock and to graze them in pasture for a period of 6 months). The alpine pastures are managed as a common property by the villages. The decision on when to open and close the fields for grazing, and when to start plowing, is taken jointly by *Yuva Mandal* (representative from every household is part of this institution) and is based on a commitment to collective action.

Mahila Mandal **(Local Women's Group)**

Mahila Mandal is a community-based rural women organization. Generally it has about 20 members. It has an elected executive body consisting of a president, vice president, secretary, and treasurer. In all of the five villages surveyed, the *Mahila Mandal* has been in existence since the early 1980s. Total of three *mandals* have been observed in the area. Each household of the village has one representation in the *Mahila Mandal*. The mandals has INR 12 to INR 50 per month as membership fee and INR 1000 to INR 1500 as joining fees. This amount is then deposited into a bank account which is opened under the name of the *Mahila Mandal* of the respective village.

The main functions and activities of the *Mahila Mandal* are:

- Mobilization, networking with community groups especially *Yuva Mandals* and Panchayat, to strengthen participation and interlinkages, and participation in *Yuva Mandals* and Panchayat meetings.
- Addressing issues affecting women and village as a whole such as gender, social injustice, alcohol abuse awareness, women's role in Panchayat, cleanliness drives, clean water sources, and tree plantation.
- Efforts in organizing work for the village, such as fixing the walkways through the village, or putting in a water system, labor exchange in fields for *mandal* members.
- Acts as a nodal agency along with Panchayat between block office and village for release and utilization of development funds.
- Mahila Mandal also provides loans between 10,000 and 15,000 Rs to the members with interest rates of 2 %.
- Lastly, one of main function of the *Mahila Mandal* in the area is forest and natural resource conservation. However, the flexibility in terms of the purpose and objectives of *Mahila Mandals* has meant that in some cases it has been adapted to the local needs of the village. Almost all *Mahila Mandals* of the five villages surveyed during field study indicated that they were active to a large degree in forest protection.

Yuva Mandal (Youth Group)

Yuva Mandal is a community-based organization and is a good example of informal institution working parallel with formal local institution such as village Panchayat. The formation of the *Yuva Mandal* in Miyar valley was around 1985–1986 mostly after the formation of the *Mahila Mandals* in the area. Generally the number of members depends on the number of households in the village as it is mandatory for each family in the village to have one representative in the mandal. In the study area, size of the mandals ranges between 16 and 45. It has an elected executive body of *Pardhan* (head), *Up-pardhan* (deputy head), secretary, and treasurer. The term for an executive body is 1 year, and after the completion of the term, a new body is selected within the members unanimously. The main objective or motivation for formation of the mandals was to discuss and agree on village requirements (infrastructure, education, health, etc.) and to put it forward through village *Pardhan* (head) during village meetings for the approval and grants.

The main functions and activities of the mandals are to:

- Lead construction activities: Yuva Mandals constructed internal roads, temples, Kuhls (irrigation channels).
- Provide loans between 10,000 and 15,000 Rs to the members without any interest rates.
- Work also as a *Kuhl* committee (construction and maintenance of *Kuhls*, distribution of water rights, etc.)
- Decide on working and payment-related community livestock grazing.

Kuhl Committee (Water Institution)

Irrigation in the Miyar valley is done by *Kuhls* (Fig. 4), channels which harness water from snow meltwater glaciers. These *Kuhls* are built with the collective labor of the village, and the water is distributed according to the share of labor contributed by a family; the distribution of the water rights is done in impartial lottery system, where each house name is written on a chit and sequence of water rights is decided by lottery system. The labor contribution is annual process as avalanches often destroy the *kuhls* during the winter. Failure to contribute family labor can lead to a withdrawal of water rights and penalties. The decision related to *kuhls* construction, maintenance, and water rights distribution is taken by *Kuhl* committee (Fig. 5), and this committee represents whole village as each house has to nominate one member from house who will represent house in committee meeting and also will provide money and manpower for construction for the maintenance of *kuhls* (Padigala 2013).

From the above examples of both the resource management efforts and the functioning of the institutions, it is observed that there are internal capabilities within the communities in Miyar valley to deal with various kinds of shocks and uncertainties. Thus, this existing adaptive potential will be very crucial in case any transformation related to climate change occurs in near future. Another important characteristic of these strategies is that they are tailor made to suit the community need at utmost local level and are dynamic in themselves to modify according to the

Fig. 4 Kuhl Head, Village Tingrit

Fig. 5 *Kuhl* Committee (Water Institution) Village Tingrit

changing need and requirements of the village. A good example is of the water right distribution in upstream villages like Tingrit and downstream village like Shansha in the Chamba valley, where in upstream village water for irrigation is in plenty due to which the water right distribution rules are less stringent, but in the downstream village where water availability is little less, local institution has modified the water distribution rules and has made it strict so that there must be equity and no fights over water distribution.

Assessment of Existing Adaptive Capacity in the Local Communities

The study has incorporated the sustainable livelihood (SLA) framework which advocates the classification of the assets or capitals into five classes (Table 2). According to the framework adaptive potential of a person or community can be

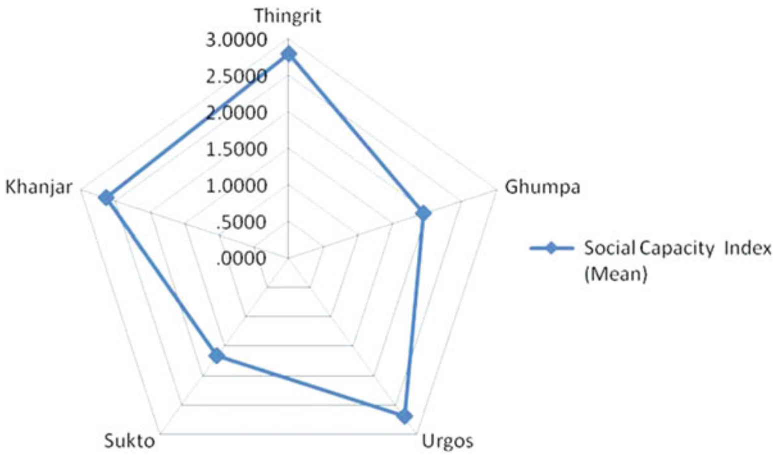

Fig. 6 Village wise social capital index

Table 5 Showing village wise institutional setup

Village	Mahila mandal	Yuva mandal	Community grazing	Gram panchayat representation
Tingrit	Yes	Yes	Yes	Yes
Ghumpa	No	No	Combined with Urgos village	Yes
Urgos	Yes	Yes	Yes	Yes
Sukto	Combined with Khanjar village			Yes
Khanjar	Yes	Yes	Yes	Yes

evaluated by using these capitals (or indicators). Present capacity assessment encapsulates evaluation of the five capital indexes based on the proxy indicators (Table 2) by using graded codes, summation, and simple averaging.

Figure 6 shows the status of the social capital in the five villages studied. It was found that two villages Sukto and Ghumpa have low social capital index (SCI) compared to the rest of the villages. This can be attributed to lack of local institutions (Table 5) like Yuva Mandal and Mahila Mandal in these villages, as these institutions help in keeping community bonded and generate mutual trust. These institutions have crucial significance in initiating and managing resource management interventions like *Jowari*, *Kuhl* works, and community grazing, etc., which leads to formation of social capital since these works involve collective action and management of common village property resources (Table 6).

Based on the social capital index and remaining four capital all the five indexes a cumulative capacity index (Figs. 7 and 8) was generated along final adaptability index ranking was created. In this ranking exercise, it was found that Ghumpa village scored better than Khanjar village despite having low index score in SCI;

Table 6 Table showing village wise social capital index

Rank	Village	Social capital index (mean)	N
1	Tingrit	2.80	20
2	Urgos	2.69	33
3	Khanjar	2.63	11
4	Ghumpa	1.95	10
5	Sukto	1.66	6
	Total	2.54	80

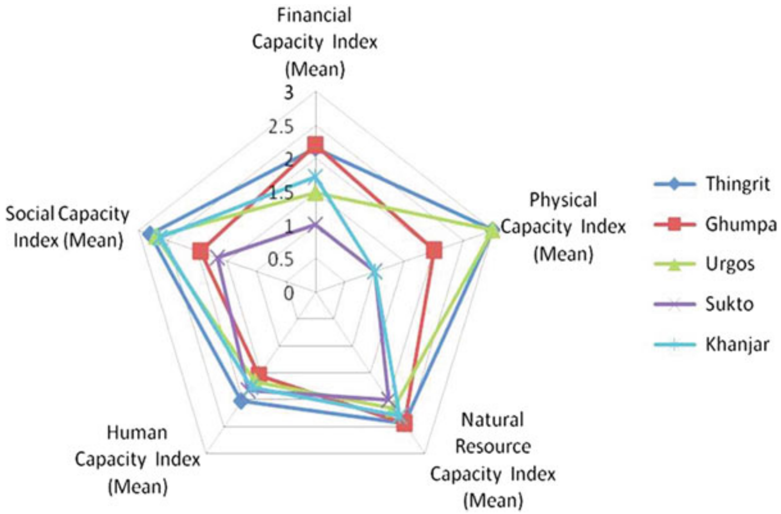

Fig. 7 Village wise capacity index

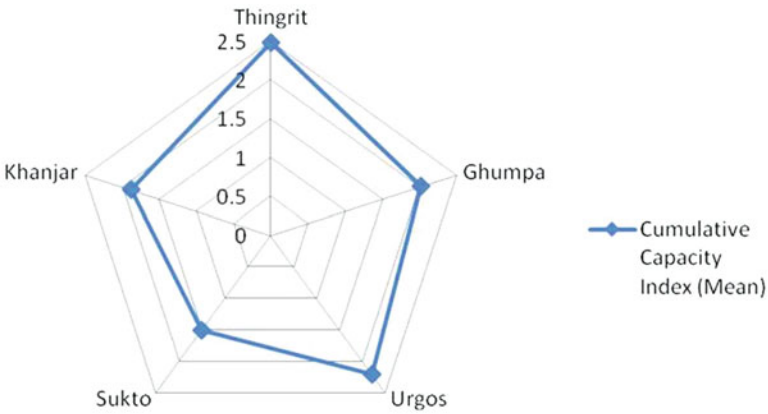

Fig. 8 Village wise cumulative capacity index

Table 7 Table showing Village wise capacity index

Village	Financial capacity index	Physical capacity index	Natural resource capacity index	Human capacity index	Social capacity index
Tingrit	2.15	3	2.43	2.02	2.80
Ghumpa	2.20	2	2.43	1.55	1.95
Urgos	1.48	3	2.15	1.66	2.69
Sukto	1.00	1	2.00	1.83	1.66
Khanjar	1.72	1	2.30	1.77	2.63

Table 8 Land holding and it's relation to adaptive potential

Land holdings	Human capacity index	Financial capacity index	Natural capacity index	Physical capacity index	Social capacity index	Cumulative capacity index
Small	1.42	1.00	2.00	2.31	2.70	1.88
Medium	1.73	2.00	2.33	2.46	2.69	2.25
Large	2.15	2.19	2.46	2.58	2.23	2.32
Total	1.77	1.74	2.27	2.45	2.54	2.15

Source: Sen et al. (2011)

this could be ascribed to higher financial capacity index and natural capital index. Khanjar village has a healthy landholding to family ratio; hence it has scored more points and ultimately exceeded in the ranking scale (Table 7).

Table 8 shows that villagers with low land holdings are weak in terms of financial and natural capital compared to large land holders. Comparing SCI with land holdings, it can be said that small land owners tend to have more social capital as a compensatory mechanism to counter low financial and natural capital. Alternatively it can be stated that with increasing financial capital there is a decreasing trend in SCI, which can be related to changing economic pattern (cash crops and high returns) in the valley.

Social capital and collective action can be used as an indicator to assess the adaptive capacity, and when faced with considerable environmental and economic risks, the ability of these societies to mitigate these risks relies heavily on intersocietal networks and social capital (Adger 2003).

In case of the Miyar valley, the villages which did not have any local institution (*Yuva Mandal* and *Mahila Mandal*) had less social capital than the other villages which have the institutions in place. Since during crisis situations, these very institutions play a crucial role (like providing intercommunity loans and food/fodder etc.) and create a bond of trust, cohesiveness, and network which motivates community to work collectively to any issue and problem among the community. And as already discussed previously, the key to adaptability against environmental variability or any other resource scarcity is the community's collective actions, trust, and social bonding. The more the social capital, the greater will be the chance of successful adaptation by the community to the changes.

Conclusion

The communities in Miyar valley have long been fighting with the harsh environments of the mountain region for survival, not only they have succeeded in it but ongoing economic trade, education, institutional mechanisms, and overall village development despite various limiting factors (such as lacking infrastructure, short cropping season) represents communities' superior resilience, adaptive capacity, and high level of social capital. The community has developed various village level adaptations strategies and institutions to manage and sustainably make use of natural resource and avoid resource scarcity in future. These adaptations strategies and institutions provide a buffer zone for the community to adapt against any change (environmental, social, or economic, etc.) up to some degree.

From the study it can be concluded that local institutions, governance, social capital, and collective actions are directly related to development, resilience, and increased adaptive capacity of the society and of the whole region. But with the predicted future, environmental changes coupled with changing economic and infrastructure scenario will defiantly alter and transform the current functioning of local institutions and governance.

It can be assumed that with increased uncertainty, climate risk and resource scarcity communities will have no other option but to adapt to the situation and work collectively to sustainably consume scarce and declining natural resources. This may lead to increased social interaction, bonding, and trust which will be a crucial factor for the community to adapt to environmental changes.

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Technical and Institutional Options of Water Harvesting Systems for Climate Change Adaptation in Agriculture

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Abstract

The focus of this paper is on a small water harvesting system that collects excess water runoff during the rainy season, and stores it for agricultural purposes during dry periods. Technical and institutional options and case studies are presented as strategic information for climate change adaptation in drought-prone rainfed areas. The paper provides a technical as well as an institutional analysis of small water harvesting system as strategic adaptation measure for climate change in drought-prone community watersheds. Through modeling studies of weather and runoff, information on the annual water yield for small water harvesting projects was estimated. To assess socioeconomic impact, ten (10) water harvesting systems were surveyed in drought-prone communities. Harvestable water from a small catchment was determined including the amount of soil erosion under various farm management practice and rainfall patterns. Case studies of ten (10) small water harvesting systems show positive results of socioeconomic impacts. Water harvesting for agricultural purposes in this era of climate change is a crucial adaptive strategy to ensure food security and alleviate poverty in the rural areas. Climate change has the most immediate impacts to be felt by rainfed agriculture.

Keywords

Climate change • Small farm reservoir • Rainfed agriculture • Upland areas

Introduction

In the upland agricultural areas, rainfall variability is a key constraint to agricultural production and economic growth in many developing countries. This is likely to be exacerbated in many places as rainfall variability is amplified as a result of climate change. Changes in rainfall will also increase variability in groundwater recharge and river flow, thus affecting all water sources. Thus, water harvesting, in its various technological forms, provides a mechanism for dealing with variability which, if planned and managed correctly, increases water security, agricultural productivity, and adaptive capacity to climate change. As such, water storage can make an important contribution to safeguarding livelihoods and reducing rural poverty.

For many millions of smallholder farmers, reliable access to water defines the difference between drought and water sufficiency. The classic response is to store water behind dams or in tanks or ponds when it is abundant and where it can be conserved in times of crisis. Water harvesting for agricultural purposes in this era of climate change is a crucial adaptive strategy to ensure food security and alleviate poverty in the rural areas.

The upland areas of many developing countries are where the vast open public areas lie, where many landless and poor peasants rush in and strive to make a living from already degraded resource. Generally, people living in these areas live below subsistence level and are locked in the vicious cycle of poverty and environmental degradation.

In the Philippines, emerging issues on climate change and dryland agriculture has been at the center of discussions and interests among top policy makers as manifested by the recently concluded conference on National Dryland Conference and the eventual creation of the Philippine Dryland Institute (PhilDri) (Dar and Obien 2007). One important research and development component of PhilDri is the institutionalization of community watershed development efforts through the introduction and optimum utilization of water harvesting technologies (Dar 2010).

General Classifications of Different Water Harvesting/Storage Options

1. Natural wetlands. Lakes, swamps, and other wetland types have provided water for agriculture for millennia both directly as sources of surface water and shallow groundwater and indirectly through soil moisture. Consequently, wetlands span the surface/subsurface interface and provide water in many different ways. As a result of their important role in the provision of water, wetlands are increasingly perceived as "natural infrastructure" (Emerton and Bos 2004).
2. Soil moisture. Globally, the total volumes of water stored within the soil are huge, but at any given locality, they are relatively small and quickly depleted through evapotranspiration. Because of this, in recent decades, there has been increased interest in various in situ rainwater management techniques that enhance infiltration and water retention in the soil profile. Widely referred to as soil and water conservation (SWC) measures, examples vary from place to place, but the most promising include deep tillage, reduced tillage, zero tillage, and various types of planting basin. The effectiveness of different measures depends a lot on soil characteristics and, particularly, on water holding capacity (Gregory et al. 2000).
3. Groundwater. Water stored beneath the surface of the earth in aquifers. A major advantage of groundwater is that there is little or no evaporation, and total volumes are often much greater than annual recharge. The amount of water that can be abstracted from a well in an aquifer is a function of the characteristics (particularly the permeability) of the rock. Some aquifers will yield only a few liters per day, while others can yield as much as several million liters. Methods for increasing groundwater recharge include pumping surface water directly into an aquifer and/or enhancing infiltration by spreading water in infiltration basins.
4. Ponds and tanks. Ponds and tanks are cisterns or cavities (covered or uncovered, lined or unlined) built by individuals or communities to store water. They are often linked with rainwater harvesting and store relatively small (but often vitally important) volumes of water. Ponds and tanks fill either by surface runoff or through groundwater and differ from reservoirs by the absence of a dam. A common limitation is that they are usually shallow, with a relatively large surface area, so that often a significant proportion of the water is "lost" through evaporation.

5. Reservoirs. Water is impounded behind small and large dams constructed across streams and rivers. Small dams (often built simply by mounding earth) store relatively small amounts of water (a few 100 to a few 1,000 m^3) and often empty every year. Many small dams do not have outlets, and water is simply removed by livestock drinking and pumping and as consequence of spilling and evaporation. They tend to be shallow with relatively large surface areas so that, in common with many ponds/tanks, a significant proportion (sometimes more than 90 %) of the water may be lost through evaporation. Large dams (often rock-filled or concrete) store millions, sometimes billions, of cubic meters of water. The water may be used for multiple purposes. Sometimes they are also used for flood control. Because they tend to be deeper with a relatively smaller surface area, in comparison to small reservoirs, they often have a higher yield relative to the inflow. Furthermore, some large reservoirs provide storage that is greater than the mean annual runoff and thus provide multiyear carryover of water.

General Advantages and Benefits of Water Harvesting Systems

The Food and Agriculture Organization of the United Nations has identified better management of soil moisture and investment in small water storage as promising interventions for poverty alleviation (FAO 2008). Under the right circumstances, small-scale water storage interventions can contribute to both food security and increased economic prosperity at a local level. For example, field studies in various semiarid environments have shown that crop yields can be stabilized and increased when seeds are sown not in furrows but in small planting basins which harvest water in situ (Twomlow and Hove 2006; Fatondji et al. 2007). Small tanks, ponds, and reservoirs can also make important contributions to livelihoods and peoples' well-being with significant potential in both Africa and Asia (Vohland and Barry 2009; Wisser et al. 2010). However, each storage type needs to be considered carefully within the context of its geographic, cultural, and political location. With the exception of large dams, past agricultural water storage development has mostly occurred in an ad hoc fashion, largely through private, community, and local initiatives, with minimal planning. In some cases (e.g., where reservoirs have silted, wells are dry and ponds have aggravated negative health impacts), it is likely that it is the lack of planning that has resulted in less than optimal investments.

Reported failures were attributed to a range of factors, including poor site selection, design and technical problems (e.g., failure of lining materials leading to seepage), and lack of commitment by communities for maintenance (Balderama 1998). In many places, there is a dearth of information on existing storage, the benefits that they provide, and their costs, including the impacts of scaling up. This is despite it being a recognized fact that though they may increase the reliability of water supplies at the local level, the cumulative effect of large numbers of small reservoirs can be to reduce river flows, with potentially serious implications for downstream reservoirs (Meigh 1995; Liebe et al. 2009).

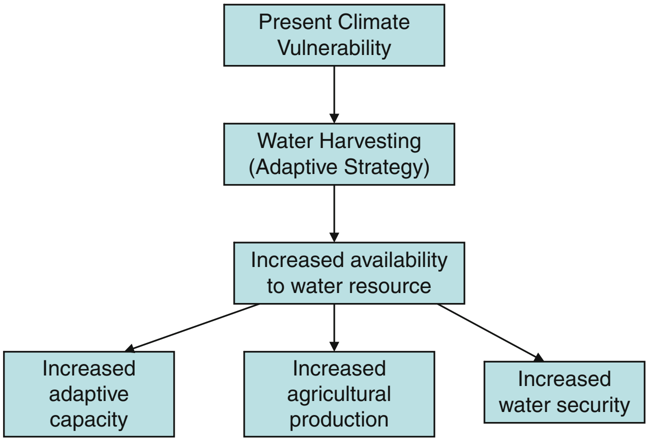

Fig. 1 Water harvesting as an adaptation strategy to reduce climate vulnerability

Even where data are available, they are often dispersed and difficult to access. Furthermore, basic scientific knowledge required for planning is also often inadequate.

Contribution to Climate Change Adaptation

As the challenges posed by global warming are increasingly understood, it is widely accepted that water is the principal medium through which the societal stresses of climate change will be manifested. Although the exact impacts remain uncertain, in many places, even where total rainfall increases, climate change will most likely increase rainfall variability. Without doubt, those who will be most adversely affected are the poor, who already struggle to cope with existing variability. They will find it increasingly difficult to protect their families, livelihoods, and food supply from the negative impacts of seasonal rainfall and droughts and floods, all of which will be exacerbated by climate change. Water storage (in all its forms) has a key role to play for both sustainable development and adaptation to climate change. By providing a buffer, water storage reduces risk and offsets some of the potential negative impacts of climate change, thereby reducing the vulnerability of people. Water storage can enhance both water security and agricultural productivity (Fig. 1).

Philippines' Program for Water Harvesting in Agriculture

General definition of water harvesting is the collection of runoff water for its productive use (Balderama 1998). Runoff can be harvested from roofs and ground surfaces as well as from intermittent or ephemeral water courses. Storage may include soil storage, groundwater storage, or surface ponding.

Water harvesting would be beneficial in the following cases:

- To supplement existing and limited irrigation water sources
- To counteract the low reliability and high variability of rainfall for rainfed agriculture
- To meet the increasing demand on agricultural food products and the increased pressure on existing cultivated land and water resources
- To increase the production and productivity of existing rainfed agriculture
- To make more efficient use of available unused agricultural resources, soil, and water

In the Philippines, the Bureau of Soils and Water Management of the Department of Agriculture serves as the governments' lead agency in the development and implementation of water harvesting and small-scale irrigation program aimed at increasing agricultural productivity in the upland and rainfed areas (Bureau of Soils and Water Management 2003). At present, there are two (2) water harvesting technologies being introduced to communities, farmer's groups, and local government units for adoption and commercialization:

Small Water Impounding Project (SWIP)

A SWIP is an earth dam structure built across a narrow depression or valley to harvest and store rainfall and run off for multiple uses (Fig. 2). Its structural height is not more than 30 m and a volume storage not exceeding 50 million cubic meters. The average service area of SWIP is about 60 ha (25–150 ha). Investment cost ranges from P1,500 USD to P4,000 USD per hectare of service area. At present,

Fig. 2 Reservoir area of small water impounding project

there are now 350 units of SWIP in the country with a service area of 21,000 ha and 16,000 farmer beneficiaries. Important functions of the project are:

- For supplemental irrigation
- Provide water for livestock
- Inland fish production
- For domestic purposes
- As a recreational facility

Irrigation System Operation of the Project

Management of the system rests on the Irrigators' Association (IA) right after project construction. The government irrigation agency, however, continues to provide guidance and technical and institutional assistance at various degrees, depending on the extent of assistance requested by the beneficiaries within the bounds of their memorandum of agreement. An engineer, an agricultural extension worker, and other specialists are tasked to strengthen the IA's periodic visits to the system to provide this assistance. Officials of the association, the President, the Vice President, the Treasurer, the Secretary, etc., are involved in order in the system management to attain the desired success. The duties and responsibilities as well as penalties/sanctions for certain infractions that pertain to system operation, drainage, and other aspects are generally spilled out in the bylaws of the association.

Basic Water Management/Distribution Plan

The basic water management plan is provided by the planned system cropping calendars, and the date of start of the cropping calendar dictates the start of water delivery/distribution. If simultaneous land soaking throughout the whole system is planned, simultaneous irrigation covering the whole system will be employed. The activity starts at the downstream sectors and moves to the upstream sectors to assure the water is not monopolized by farmers in the upstream areas.

Principles in Basic Water Distribution Planning (Cruz 2002)

(a) The basic water distribution plan is dictated by the planned system cropping calendar. The start of water deliver/distribution corresponds to the start of farming activities as articulated in the planned cropping calendar. The stages of farming activities and types of crops dictate the amounts of water to be delivered.
(b) For rice crops, high irrigation requirement is needed during land soaking. Because of this big demand, some planned cropping calendars provide for sequential start of this activity within a sector. In such a case, water delivery would, correspondingly, be planned to jibe with the planned sequence.
(c) Diversified crops require less amount of water compared to rice. The scheme usually applied is intermittent irrigation. For diversified crops planted in the uplands, e.g., beans, sweet peas, and crucifers (broccoli, cauliflower, etc.), where the plants' water requirement is low, sprinkler type of irrigation is normally adopted.

(d) During the wet season, water supply is usually abundant. It would be convenient therefore to adopt simultaneous distribution of water, system-wide.
(e) During the dry season, it oftentimes becomes necessary to plan for rotational method of water allocation.
(f) It may become necessary to shift from one method of water allocation to another. The decision to shift must be based upon an objective, established, and verifiable such as presence of farmer complaints. The complaints are to be monitored by the President preferably with the sector leader/s. Some questions will have to be answered:
    (i) How many farmers are complaining?
    (ii) Are all the complaints unbiased and verified?
    (iii) Who verified the complaints?

    If these questions have been satisfactorily answered, the President will declare the change in the method of water allocation.

    When there is low level of water supply in the reservoir before water distribution has started, common agreement are established by the Irrigator's Association as to what method of water distribution is to be adopted. A method of informing the farmers about the shift in method of allocation is developed. These procedures approved by the IA aimed at minimizing if not entirely eliminating any suspicions that the President is exercising his or her discretion in favor of any farmer, sector, or group of farmers.
(g) Adopted method of water distribution are properly disseminated. There are meeting of minds among farmers on a fixed signal that a certain scheme of water distribution is to be enforced. For small systems, it would be convenient to just pass on the information to each sector leaders who would assume the responsibility of informing the farmers within the area. There is also meeting of minds to a certain method of distribution. A flag will be raised at designated and conspicuous place, say, the IA's meeting hut area or the canal's turnout. These signals or information dissemination would invalidate any farmer's claim that he or she was not aware that such a scheme is being enforced.
(h) The water distribution scheme are evolved, tried, modified, and improved by the farmers themselves, if necessary, through several trials until an acceptable one is developed adaptable to the system.
(i) Sanction against erring members must be strictly enforced. Strict adherence to the rules and regulations promulgated for the implementation of the plan must be enforced, and any violations thereof must be dealt with accordingly. Sanction can be of different ways and of varying degrees of severity as in the following:
    (i) During imposition of sequential start for land soaking, the farmer who cannot follow the schedule will not be given irrigation water.
    (ii) During simultaneous irrigation for all sectors, sector taking in water more than what is prescribe will be deprived of irrigation water for (1) day.
    (iii) During rotational irrigation, farmers stealing water will not be given water for one rotation.

(iv) During rotation, farmers taking in water out of turn will deprive of water for one rotation or a cash fine. Violation for three times within the season will deprive the farmer of water for whole season.

Methods of Water Distribution

(a) Simultaneous irrigation – for rice cultivation, during the wet season cropping, reservoir is expected to be always at full capacity. The usual plan of distribution is simultaneous delivery to the canals and to all sectors and individual farms. This method of water delivery had the widest acceptance among the farmers, and there is less labor input in the control of gates and in apportioning water at the turnouts. Even during the dry season cropping, if the cropping calendar had made an early start, with a minimum of turnaround time, in most localities the reservoir would still be at peak storage when planting activities start and land soaking may be done simultaneously system-wide requiring simultaneous water delivery. However, it may be prudent to conserve water and employ other schemes when simultaneous delivery may be done only to some extent.

(b) Rotational irrigation – generally, rotational irrigation method of water distribution is employed when there is some shortage in irrigation supply. However, even during the dry season, where there is ample supply at the start of farming activities to satisfy the water demand for the programmed area, it might be advantageous to practice water rotation. Rotating the delivery is a judicious scheme to ensure equitable distribution of the available irrigation water. It will correct the usual pernicious practice of the upstream farmers drawing more than their needs as the water passes throughout their fields.

Small Farm Reservoir (SFR)

A small farm reservoir is a water impounding structure with a maximum height of embankment of 4 m and average pond area of 1,500 m^2. It serves limited areas no more than 2 ha and is designed to become an integral part of individual rainfed farms with catchment area not exceeding 10 ha. Its advantages are as follows: (1) less capital intensive, (2) easy to construct and maintain, and (3) empower farmer cooperation and production capability (Fig. 3).

In 1989, the Philippine Government embarked on a national program called the Small Farm Reservoir (SFR) project. This program aimed to accelerate rural development through the adoption of on-farm reservoir technology and to boost farm income by intensifying land use in rainfed areas (Maglinao 1994).

Design of Small Farm Reservoir

The reservoir is owned and managed by individual farmers and is typically built using a bulldozer. It consists of an earthen dam that traps harvests and stores rainfall and runoff. The embankment is not more than 4 m high, the surface area averages about 1,000 m^2, the depth is 2–3 m, and the storage capacity is some 2,000 m^3.

Fig. 3 Picture of a small farm reservoir

Design Conditions

Prior to design, an intensive physical assessment of the proposed area is completed. The following design conditions are considered most important for successful reservoir use:

(a) Topography – the most suitable topography is undulating with a slope of 2–15 %.
(b) Soil texture – embankments are normally constructed from soil at the reservoir site as transporting embankment materials are expensive. Ideal soil types for an SFR embankment are loam, sandy loam, clay loam, and sandy clay loam. These types of soil should be present at the site within a depth of 1.5 m. Peat soils, heavy clays, and saline, alkaline, or sodic soils should be avoided.
(c) Rainfall pattern – while the SFR system is suitable for all climate types, greater benefits are derived if the rainfall is unimodal with 5 wet months (>200 mm/month) and a total annual rainfall of 1,500 mm or more.
(d) Watershed and service areas – SFRs are best suited for areas with undulating topography where the shortest embankment spans across the valley. The size of the watershed must be adequate and compatible with the proposed reservoir size, and a service area should be included to ensure full use of the SFR. For sites with ample rainfall, a minimum catchment area of 0.2–0.5 ha of terraced rice land is adequate to store a water volume of 1,000 m^3. Using sound water management practices in conjunction with this volume of water stored in the reservoir at the beginning of dry season, 0.33 ha of rice land can be supported (Guerra et al. 1990). It is assumed that planting is performed early in the season and that rainfall occurs during the growing season.

Embankment Design

An SFR should ideally have a storage capacity that is adequate to supply water to the intended service area. Moreover, in terms of cost, there must be a sufficiently high storage ratio, i.e., the ratio of maximum volume of water stored in the reservoir to the volume of earth moved to construct it. The average storage ratio for completed SFRs ranges from 2.6 to 3.5.

Being designed to hold water and resist pressure, the reservoir embankment must be stable and easy to maintain. A maximum top width of 2 m is recommended for a dam height of less than 4 m. The recommended side slopes fro clayey soils are 2.5–3 horizontal to 1 vertical at the pond side and 2 horizontal to vertical 1 at the downstream side, while for silty or sandy soils, it is recommended that both slopes be 3–4 horizontal to 1 vertical.

Hydrological Characteristics

For the sound operation and management of SFRs, it is essential to gain a quantitative understanding of the following hydrological characteristics:

(a) Water collection: SFR field studies indicate that direct interception of rainfall accounts for about 36 % of SFR inflow, with the remaining 64 % coming from runoff collection. Moreover, due to the dynamic nature of inflow and water used for irrigation, the total annual water flow into an SFR is two to three times higher than the storage capacity.
(b) Water loss: seepage and percolation (S&P) account for about 45 % of the total volume of water outflow from the SFRs. Minimum and maximum S&P losses are typically 4 and 5 mm/day, respectively, with average evaporation loss accounting for 25 % of total outflow volume. The relationship between S&P loss and SFR water depth varies with the square of water depth.
(c) Water use: water use for land preparation and irrigation accounts for 30 % of total outflow volume, while the volume of water available for irrigation during the dry season crop is approximately equal to 65 % of reservoir capacity.

Utilization of Reservoir Water

The rain and surface runoff from three heavy rainfalls occurring in June, July, and August are normally sufficient to fill an SFR. Important factors regarding water utilization are:

(a) Irrigation practice: SFRs provide supplemental irrigation during the wet season, with the accumulated water enabling farmers to prepare the nurseries and land earlier than would be possible without reservoirs. During short periods with limited or no rainfall, SFR water can also be released by furrow or hand watering.
(b) Freshwater fish culture: for SFRs designed for dual use as both an irrigation and a fish culture resource, either organic or inorganic fertilizer can be added to enhance growth of plankton at the reservoir filling stage. Once the water turns bluish green, fingerlings can then be seeded in the pond at the recommended rate.

(c) Rice-based cropping systems: for SFRs used in rice-based cropping systems. Farmers must plant early in the main season in order to allow for an early start of the next drops in the dry season. The common cropping patterns adopted are rice + fish, rice (+fish) – rice, rice (+fish) – watermelon, rice (+fish) – vegetable, and rice (+fish) – rice – watermelon.

Water Management Practices

Water from the reservoir is released through flexible siphon hoses. This simple method has distinct merits as the education system in many rural areas is insufficient to effectively implement more technical methods without major help from government. Vegetable and fruit trees can even be irrigated using a bucket or watering container. Such crops are important as they supply a ready source of cash and food on a daily basis. Depending on the market demand and availability of capital and labor, this method could control the periods when a portion of the service area is planted with vegetable, watermelon, and/or other cash crops.

Financial Viability of SFRs

The adoption of SFRs at an annual interest rate of 18 % and 15-year life span with a periodic 3-year maintenance cycle provides a high value benefit-cost ratio of 5.1 and an internal rate of return of 177 %. Indeed, this is why such an overwhelming majority of SFRs are a lucrative capital investment.

Even with a life span of only 5 years, an SFR investment pays for itself in 3 years with rice and fish alone, whereas with rice + fish + rice combination in which 2 and 0.5 ha of rice are irrigated during the wet and dry seasons, respectively, with tilapia being grown at the same time, the payback period is reduced to 2 years. Such a return is considerable in that properly maintained SFRs would naturally provide irrigation service for much longer than 5 years. A summary of the features and technical specification of an SFR is presented in Table 1.

Government Support and Program Impact

Even for highly suitable areas, the initial cost of an SFR is too high for an average farmer to afford. Accordingly, the Philippine Government has implemented a financing scheme in which farmers use a government loan to construct their own SFR. While the repayment period is 5 years, a hardworking farmer can repay the loan in less than 2 years. To ensure technical assistance is provided in every aspect of the technology transfer, government technicians are regularly dispatched for this purpose.

Socioeconomic Impacts of Water Harvesting Systems for Agriculture: Case Studies of 10 Water Harvesting Projects

This section presents results of case studies on the socioeconomic impact of ten (10) small reservoir irrigation projects located in the northern region of the Philippines. The irrigation systems studied were small, low cost, communally

Table 1 SFR features and technical specification

Typical features and technical specification of SFR	
1. Watershed	
Area (ha)	3 ha
Proposed land use	Vegetable and trees
Soil type	Clayey loam
2. Reservoir area (m^2)	1,000
3. Project facilities	
(a) Dam	
Type	Straight embankment
Height, m	3 m
Crest width	2 m
Upstream slope	1:3
Downstream slope	1:2
(b) Spillway	
Width, m	1.5
Depth, m	1.0
4. Design service area	1 ha
Components	Fish + vegetables + animal + mushroom + grasses
5. Water use	Irrigation, livestock watering, fish culture
6. Conservation showcases	Water harvesting, contour farming
	Crop-animal-fish integration
	Micro-irrigation
7. Project cost construction	P900 USD

owned and managed, and located in vulnerable areas with slope greater than 20 % (Balderama et al. 2006). Operated by an Irrigator' Association, the purpose of the irrigation project is to increase production through increasing water supply and protect the environment that supports the project with the community as the main actors in the development process. The study area covers a total of 267 ha planted into rice, a combination of rice and vegetables and vegetables only.

System Performance

As a whole, the systems had an increased cropping intensity of 21 %, a distribution efficiency of 40 %, and a fair satisfaction rating given by the members interviewed. One notable problem is a poor collection of Irrigation Service Fee (ISF) in 70 % of the project area. However, all the projects are believed to be functioning efficiently with minimal conveyance losses because of the use of pipes and canal lining.

Overall Benefits Derived from the Project

(a) Economic impact – results show that most of the impact was due to increases in productivity and increases in cropping intensity. Across all crops, average productivity per hectare was highest in vegetable-producing areas. The average aggregate annual benefit per project was P5,150.00 USD. Considering the total construction cost as the initial investment of the various projects and the increases in the value of benefits due to increases in productivity, cropping intensity, and area as the project benefits, the average payback period is 1.95 years. This payback period for investment projects is quite fast. This result implies that the investment cost in these projects can be recouped very quickly. Also, this implies that the direct benefits from the projects are high.

(b) Social impact – the project created positive impact at three levels: community, organization (IA), and households. The positive impact at the community level included increased access to resources like the construction of water bridges out of collected service fees and external sources for microfinancing. At the organization level, the IAs generally learned to cope up with maintenance problems especially when their livelihood security was threatened with inadequate irrigation water. These enhanced the cooperation among farmers and ness in others, leadership development, market integration among vegetable growers, and more cohesive relationship of the IAs and the local government units.

Impact of Participatory Approach in Project Development

Participatory development in the communities was legally established through Republic Act 7160 signed in 1992. The law provides decentralized decision-making at the lowest local government unit – the barangay or village level. Projects were established based on needs of the community. Through the representation of their officials, the community decides on what type of projects will be established. Each barangay is granted Internal Revenue Allocation (IRA) from the national government based on their population, land area, and revenue collections for development projects. In the implementation of the communal irrigation projects, the participatory development strategies employed are as follows (ERP-CASCADE 1998; CASCADE 1998, 2000):

(a) Involvement of the local government officials from the provincial to the community in the planning and operation of the projects. This strategy gave the local government a firsthand look on the economic and environmental conditions in the project sites.

(b) Facilitating the integration of various government services and programs into the community.

(c) Formulation of “Rules-in-Use” by the members of the IAs.

(d) “Counterparting Scheme” for various stakeholders (i.e., IAs contributing labor in the construction and operation and maintenance of the irrigation projects).

(e) Trainings on capability building not only on maintenance and operation of the projects but also on negotiations, decision-making, resource generation, and communications strategies.

Evidences of Participation

(a) Contribution to the construction of the project – participation is in itself shown primarily in the construction of the facilities. On the average, the beneficiaries contributed more than 22 % of the total project cost in the form of labor and food.
(b) Indicative increase in organizational control – the level of organizational control increased in most of the projects. Maintenance and operation have become easier to implement in IAs with high to medium level of organizational control.
(c) Development of new leaders – in some IAs, new sets of leaders were regularly elected to manage the projects. This is one of the offshoots of participatory approach.

Characteristics of Sustainable and Stable Irrigators Associations

From the case studies conducted, several characteristics of the Irrigators Association found to be good measure for their long-term sustainability are as follows:

(a) The members are involved in the planning, operation, and maintenance of the irrigation systems.
(b) Support services were broadened and integrated into the project operations.
(c) Rules formulated were tied up with water distribution criteria.
(d) The members and young leaders are mentored on how to make rational decisions

Water Harvesting as Adaptive Strategy for Climate Change

Evaluation of seasonal climate impacts on crop production as well as on crop growth and development will enable agricultural managers and researchers to formulate strategies and mitigation techniques to counter such impacts. Figure 4 shows the result of data analysis at Echague climate station at different levels of rain probability using dependable rainfall approach. Eighty percent probability represents a dry year that approximates the 2009 actual record which was an El Nino year. As presented, the figure conforms to climate agency's estimate that the El Nino phenomenon causes rainfall to be 60 % lower than the historical average.

A simulation study was conducted to establish a relationship between reservoir volume and rain probabilities and their effect on income. Important result of the simulation for selected crop combination planted after rice is presented in Table 2.

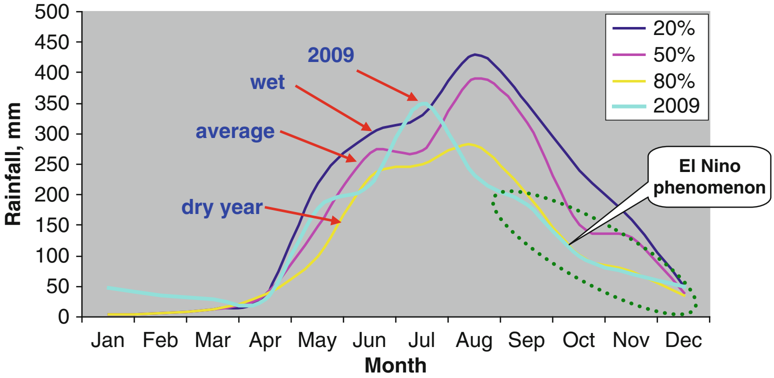

Fig. 4 Rainfall at different probabilities compared to 2009 data

Table 2 Effect of varying volume of reservoir and rainfall probability to gross income

Selected cropping pattern	Income (US dollars)			
		Rainfall probability (%)		
	Volume of reservoir (cubic meters)	*20*	*50*	*80*
Garlic-mungo	1,000	1,714	1,657	1,429
	1,500	1,857	1,829	1,800
	2,000	1,971	1,943	1,914
Garlic-soybean	1,000	1,714	1,657	1,429
	1,500	1,829	1,800	1,771
	2,000	1,914	1,886	1,857
Garlic-peanut	1,000	1,717	1,657	1,143
	1,500	1,800	1,786	1,771
	2,000	1,857	1,829	1,800
Tomato-mungo	1,000	1,229	1,200	1,143
	1,500	1,371	1,314	1,286
	2,000	1,457	1,429	1,371
Tomato-soybean	1,000	1,200	1,171	1,143
	1,500	1,286	1,229	1,171
	2,000	1,371	1,343	1,286

From the sample result and analysis, important finding reveals that increasing reservoir volume will have significant effect on income of non-rice crops during normal (50 % probability) and dry (80 % probability) years. If a wet year (20 % probability) is expected, optimum yield and cropping intensity will be realized provided that a minimum of 2,000 cubic meters of reservoir water is available for supplemental irrigation.

Model Institutional Framework on Successful Implementation of Community Water Harvesting Irrigation System

From lessons learned in the past, Balderama et al. 2006 developed a framework on implementation of communal irrigation projects as a guide to planners and managers.

Process Framework on Planning and Implementation

The process framework on planning and implementation of a community reservoir irrigation project is described below. The principal actors in the planning stage are the community and municipal local government units. There are three important milestones to attain in this process: (1) formal request for funding by the proponent group, (2) decision to implement by all stakeholders, and (3) forging of construction agreements by concerned parties including a contractor, if there is any.

Formal Request

The first activity is the issuance of formal request by the village local government or farmer organization to the funding agency with accompanying proposal that contains basic data and information pertaining to engineering and agro-socioeconomic aspects of the proposed irrigation project.

The engineering data/informations are the following:

(a) Service area
(b) Soil suitability
(c) Water availability
(d) Existing farming systems

The agro-socioeconomic data/informations are the following:

(a) No. of households to be impacted
(b) Existing land tenure arrangement
(c) Projected benefits
(d) Market opportunities

The time frame is about 2 weeks for the engineering survey and up to 6 weeks for the agro-socioeconomic data gathering. At this stage, the role of the municipal local government is very crucial in the packaging and endorsement of the proposal considering that farmer groups usually lack skills on this kind of work.

Decision to Implement

The "decision to implement" would depend on the results of more detailed investigation by the agency-commissioned multidisciplinary team of evaluators.

Data/Information to be gathered and activities to be undertaken are as follows:

(a) Environmental impact assessment.
(b) Organization of water users group.
(c) Agreement on management scheme.
(d) Counterparts' agreements of the different stakeholder are finalized.

This process may take up to 4 months to complete.

Construction Agreement

The third phase, "construction agreement," should require the following documents:

(a) Detailed intake and canal design
(b) General layout design and view
(c) Mitigation works design
(d) Agreement of future maintenance and development cum water fee
(e) Agreement on sharing of works (i.e., agency provides engineers and materials, LGU with equipments, and members free labor)

Preparation of engineering designs shall be the responsibility of local government and project engineers in close consultation with the water users group. The final agreement may require 2–3 months.

Framework on Sustainable Management of Communal Irrigation Project

Figure 5 presents a framework on successful operation and management of a communal irrigation system. Main consideration is to address major factors causing inefficient operation and poor maintenance of an irrigation system such as the following:

1. Lack of systematic operation and maintenance procedure
2. Inadequate training of the O&M staff
3. Insufficient fund for O&M works
4. Lack of farmer participation
5. Lack of farmer education

Considering the abovementioned factors, it is evident that the success and sustainability of any communal project would largely depend on the strength of the association that runs and manages the system.

The framework shows the indicative output of a successful communal irrigation system and the input parameters that cause its successful performance. The improved management factors contributing to its performance are systematized O + M, adequate funding and training, regular dialog of stakeholders, and good water management philosophy. The social factor that is equally important is the participation

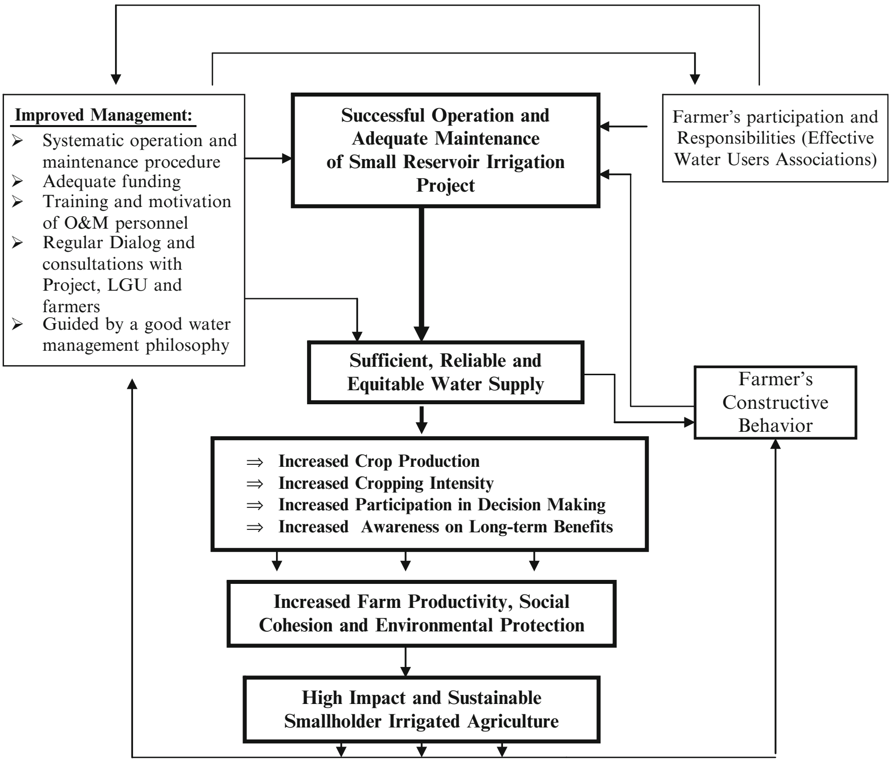

Fig. 5 Framework on the management of communal irrigation system

and responsibility of the water users. Strengthening the individual farmer's constructive behavior strengthens the farmers group.

The strengthening of the water users group will provide them enough skill to do the routine O + M in a systematic way, generate their own resources for O + M funds, and mobilize enough manpower at the right time for O + M. In addition, core values (i.e., responsibility, accountability, and resourcefulness) are instilled to every member through regular seminars and dialogs. The sufficiency, reliability, and equitability of water supply across the system should be a water management philosophy every single member should adhere to.

The dynamic interplay of improved management and good social behavior will result to efficient, reliable, and equitable delivery system of irrigation water to farmers. These result to positive impact due to increase in crop production with environmental protection, increase in cropping intensity using different crops, and increase in participation in any decision-making process and increase in awareness on long-term benefits.

The attainment of improved water management in a system will also have positive impact on the constructive behavior of members who will in turn become more responsible members and better assets of the group.

Perceived Constraints in Linking Water Harvesting Technologies to Agricultural Development and Suggested Research Topics

1. Dissemination of water harvesting techniques to other areas has never been explicitly a subject of research. The socioeconomic and environmental conditions should be the key criteria for selecting the most suitable techniques.
2. Lack of adequate hydrological, soil, and land use data which often results in applying design criteria for water harvesting structures which have been designed from questionable assumptions.
3. Soil erosion in the cultivated areas resulting from poor farming practices.
4. Lack of technical advice, training, and other services including incentives for farmers.
5. Lack of documentation and analysis of existing indigenous water harvesting system.
6. The lack of risk analysis studies of crop failure due to low reliability of rainfall.
7. Lack of large-scale demonstration projects.

To generate information to address the above constraints, research and development topics are suggested:

1. Detailed hydrometeorological analysis of rainfall data (daily and storm by storm) is needed, including probability and risk analysis of intra-storm drought periods, rainfall intensities, and duration of single rainfall events.
2. Analysis of the effect of different water harvesting and farming techniques on soil erosion and on soil and water conservation.
3. Establishment of rainfall and surface runoff measurement networks to obtain basic data for project planning and design. Community watersheds would provide realistic data on surface runoff from measured rainfall events and would thus facilitate the use and calibration of simulation models.
4. Use of geographic information system(GIS) and other IT-based tools for the identification of potential areas for water harvesting and planning for community watershed development.
5. More attention must be given to socioeconomic aspects in project planning, implementation, and maintenance such as viability of indigenous systems and local experience, people's priorities and participation, land tenure, subsidies and incentives, and the role of women.
6. Development of a package of appropriate and cost-effective technologies to optimize soil and water management and to intensify agricultural production.

Conclusion

In the rainfed and upland areas which are also considered as fragile ecosystems, rainfall variability is an important factor in development and translates directly into a need for water storage and harvesting system. In areas of developing and underdeveloped societies, existing variability and insufficient capacity to manage rainfall will exacerbate the already prevailing poverty and food insecurity. Thus, these places are predicted to experience the greatest negative impacts of climate change.

Successful undertakings show that by making water available at times when it would not be naturally available, water harvesting can significantly increase agricultural and economic productivity and enhance the well-being of the environment and the people.

Future population growth, in conjunction with climate change, will increase the importance of putting in place water harvesting technologies and systems especially in the rural communities. However, as water resources are increasingly utilized and climate variability increases, planning will become even more difficult. Without greater understanding of which types of storage are best utilized under specific agroecological and social conditions and in the absence of much more systematic planning, there is the risk that many water harvesting investments will fail to deliver the intended benefits.

Current research and development activities are aimed to better understand water resources and storage under different social and ecological conditions. This will provide insights into potential climate change impacts on water supply and demand, the social and environmental impacts of different storage options, the implications of scaling up small-scale interventions, and the reasons for success/failure of past storage schemes. Systematic methods for evaluating the suitability and effectiveness of different storage options are being developed to assist planning and facilitate comparison of storage options, individually and within systems.

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The Contribution of Traditional Agroforestry to Climate Change Adaptation in the Ecuadorian Amazon: The Chakra System

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Abstract

This chapter presents the contribution of "chakra," a traditional agroforestry system, to climate change adaptation and biodiversity conservation in Ecuador's Amazonian communities. IPCC's methodology was used for the estimation of carbon sequestration in soil, biomass, and cacao plantations. Carbon levels in multiple systems of land use were measured through temporary plots. Chakra is efficient to adapt to climate change due to higher levels of carbon sequestration and tree diversity in comparison to other forms of land use. Chakra allows for sustainable use of forests by combining cultivation of the Ecuadorian finest aromatic cacao, controlled timber extraction, production of staple food, and conservation of medicinal plants. Chakra enables Amazonian communities to contribute to both food security and well-being and conservation of the region's high biodiversity. The chapter informs policy makers and communities about the importance of strengthening traditional agroforestry to achieve environmental and social sustainability. The Amazon region is a vulnerable ecosystem, where adaptation to climate change depends on the extent to which the options for land use are compatible with the conservation of biodiversity and the provision of the ecosystem services that sustain local communities' livelihoods. The chapter provides solid evidence that this might be possible through traditional agroforestry.

Keywords

Ecuadorian Amazon • Climate change • Traditional agroforestry • Sustainability • Cacao

Introduction

Traditional systems of agricultural production, particularly agroforestry, have been recognized worldwide as an integrated approach to sustainable land use. More recently, agroforestry systems are believed to have a high potential to contribute to climate change mitigation through carbon sequestration. This has brought a renewed interest in research both on the biophysical conditions under which efficient carbon sequestration can happen and the factors that can enable positive gains for farmers. Yet, the evidence found in this recent literature is not conclusive and generalizations tend to become unrealistic, often because several interrelated and site-specific factors influence the rate and extent to which agroforestry can sequester carbon (Noponen et al. 2013; Oelbermann et al. 2004).

Agroforestry, generally referred as the practice of growing of trees and crops in interacting combinations, is based on the premise that complex land-use systems result in greater efficiency of resource (nutrients, light, and water) capture and utilization and greater structural diversity that enables tighter nutrient cycles, therefore, more system stability and resilience at site level and connectivity between forests and other landscape features at landscape and watershed levels (Nair et al. 2008). The advantage of agroforestry as a mechanism for climate change mitigation is that, compared with other terrestrial options, agroforestry has other environmental benefits such as restoring and maintaining above-ground and below-ground biodiversity, corridors between protected forests, and reduction of pressure on natural forests and maintaining watershed hydrology. These ecological foundations of agroforestry systems have been associated with a potential for the provision of ecosystem services worldwide and contribution to food security and poverty alleviation in developing countries (c.f. Lal 2001; Pandey 2002).

In large-scale studies of regions where data is available and reliable, the potential of agroforestry to increase carbon sequestration is promising. For example, in European agriculture it has been estimated to reach near 35 % of all CO_2-equivalent emissions in the EU in 2007, which at prices of 2012 would have a value of 282 euro/ha (Aertsens et al. 2013). Freibauer et al. (2004) analyzed the potential for carbon sequestration and economic viability of agricultural soils in Europe (EU-15) and concluded that efficient carbon sequestration in agricultural soils demands a permanent management change and implementation concepts adjusted to local soil, climate, and management features. In tropical agroforestry systems, Albrecht and Kandji (2003) estimated the carbon sequestration potential in a range of 1.1–2.2 pc carbon in the terrestrial ecosystems over the next 50 years. However, there are shortcomings of these estimates associated with the uncertainties related to future shifts in global climate, land use, and land cover and the poor performance of trees and crops on substandard soils and dry environments, pests, and diseases. Also, research in the Appalachian agriculture (López-Bellido et al. 2010) shows that current practices do not allow for contribution to C sequestration; hence, improved agricultural practices are needed in order to increase soil organic carbon sequestration.

In developing countries, where reliable environmental and economic data are less available c.f. (Claessens et al. 2012), there is increasing expectation about the economic impact of agricultural carbon sequestration. In the Andean region, the fragile nature of agroecosystems and limited capacity of resource-poor farmers to adopt the large-scale use of fertilizers and pesticides suggest the need for agroecological intensification to restore soil functioning and ensure long-term sustainability (Fonte et al. 2012). However, Antle et al. (2007) used a model to simulate the effects of adopting agroforestry practices in the Peruvian Andes and showed that the economic potential is relatively low at carbon prices below $50 per MgC. The price would need to rise significantly (100 %) to make the adoption of agroforestry in terraces attractive; if that happens, carbon sequestration could raise per capita incomes by up to 15 % and reduce poverty by 9 %. In Central America, Somarriba et al. (2013) suggest that, among the agroforestry crops that have the greater potential to mitigate climate change, the cacao tree is credited for stocking significant amounts of carbon.

Research on sub-Saharan Africa, where climate change is predicted to have considerable negative impacts, shows also that carbon sequestration in agricultural soil can make only modest contributions, in a range of 3–6 of fossil-fuel contributions, to mitigation of overall greenhouse gas emissions (Hutchinson et al. 2007). Palmer and Silber (2012) showed that, in order to make the potential of traditional land use effective for improving the farmers' income of Mozambique, systems that combine sequestration and cash crop production have higher net benefits, although they have less carbon-sequestration potential. In West African Sahel as in sub-Saharan Africa, carbon sequestration is a promising incentive for introducing agroforestry practices and contributing to sustainable land use (Takimoto et al. 2008; Thangata and Hildebrand 2012); therefore, countries that incentive this practice can benefit from REDD+ and other global environmental policies for climate change mitigation. Additionally, as it has been demonstrated in traditional societies like in many parts of rural China (Xu et al 2007), the economic impact of environmental policies that promote carbon sequestration through agroforestry can also have social implications in terms of participation, increased mobility, and less subsistence agriculture-based livelihoods.

This brief review suggests that research is not conclusive and more is needed, especially for the tropics, to more accurately capture the impact of region-specific interactions between climate, soil, and management of resources on carbon sequestration, which are lost in global-level assessments. In the recent global context of climate uncertainty, many productive ecosystems are endangered. Diversified farming systems are an example of complex systems which are able to adapt and resist the effects of climate change. These systems have a high structural complexity which enables them to act as a buffer against temperature fluctuations (Nicholls 2013) and, as Ríos et al. (2007) suggest, there is increasing interest in understanding how local population's traditional practices can generate a path for sustainable use of plant diversity and adaptation to climate change. The purpose of this chapter is to present the contribution of "chakra," a traditional agroforestry system developed in Ecuador's Amazonian communities, to climate change adaptation and biodiversity conservation. Given that the Amazon region is a vulnerable ecosystem, where adaptation to climate change depends on the extent to which the options for land use are compatible with the conservation of biodiversity and the provision of the ecosystem services that sustain local communities' livelihoods, we argue that the chakra system is efficient to adapt to climate change due to higher levels of carbon sequestration in comparison to other forms of land use. Chakra also allows for sustainable use of forests by combining cultivation of the Ecuadorian finest aromatic cacao, controlled timber extraction, production of staple food, and conservation of medicinal plants. The local governance system established around chakra enables Amazonian communities to improve their chances for food security, increasing income, and conservation of the region's high biodiversity. In the remaining sections, we develop this argument, preceded by a description of the methodology used in the study and a contextual description of the Ecuadorian Amazon.

Chakra in the Context of the Ecuadorian Amazon

Characteristics of the Ecuadorian Amazon

Ecuador represents only 0.2 % of the earth's surface; it is positioned in the 6th place among the most mega-diverse countries in the world (Mittermeier 1988), hosting around 10 % of the world's plant species (CAAM 1995). In this epicenter of biodiversity, the Andean-Amazonian space is considered as a "leading hotspot" (Myers et al. 2000) with a great potential to provide the ecosystem services needed to sustain local livelihoods and global goods such as carbon forest.

However, one of the major problems facing this area is deforestation mainly due to the increase of the agricultural frontier (Pichón 1997; Bilsborrow 2004; Pan and Carr 2010). The forest clearing started in the early 1960s, when the emergent oil industry induced the formation of human settlements in the rainforest, and continued at a rapid pace during the land reform, from 1964 to 1973, when a process of agricultural colonization (Murphy et al. 1997; Sierra 2000; Mena et al. 2006) changed significantly the pattern of land use from forests to agricultural crops and livestock grasslands (Carr and Bilsborrow 2001; Torres et al. 2005; Pan and Carr 2010). Farmers from coastal and highland areas of Ecuador settled in the Amazon and introduced practices of monoculture (Pichón 1997), unsuitable for the fragile Amazonian soils. The expansion of agriculture and the introduction of livestock induced significant levels of immigration and the construction of road infrastructure, which severely impacted the Amazon ecosystems and landscape (Pichón 1997; Wunder 2000; Pan et al. 2005).

The challenges of biodiversity conservation and recovery of cultural patrimony associated with traditional land use led to design a strategy based on spatial planning, supported by the UNESCO. As part of this strategy, the "Man and Biosphere" program delimitated an area located in northeastern Ecuador to be the Sumaco Biosphere Reserve (SBR), covering 931,930 ha, i.e., 8 % of the Ecuadorian Amazon (MAE 2002). The core of this strategy is the conservation of the Sumaco Napo-Galeras National Park in an area of 205751.11 ha (MAE 2013; see, Fig. 1).

The native Kichwa population inhabiting the Ecuadorian Amazon is concentrated in Napo province, representing 60 % of Napo's total population (Irvine 2000; INEC 2010). However, since the 1980s, Napo has become one of the main attractive centers for migration (Arévalo 2009), particularly to the SBR, for its potential for economic activity. The new human settlements have located in the SBR transition and buffer areas.

Traditional Agroforestry in the Ecuadorian Amazon: The Chakra System

Cultivation of small plots within the rainforest is a traditional practice that, over the centuries, the Kichwa population from the Ecuadorian Amazon has developed in order to sustain their livelihoods. Such a pattern of land use, locally known as "chakra,"

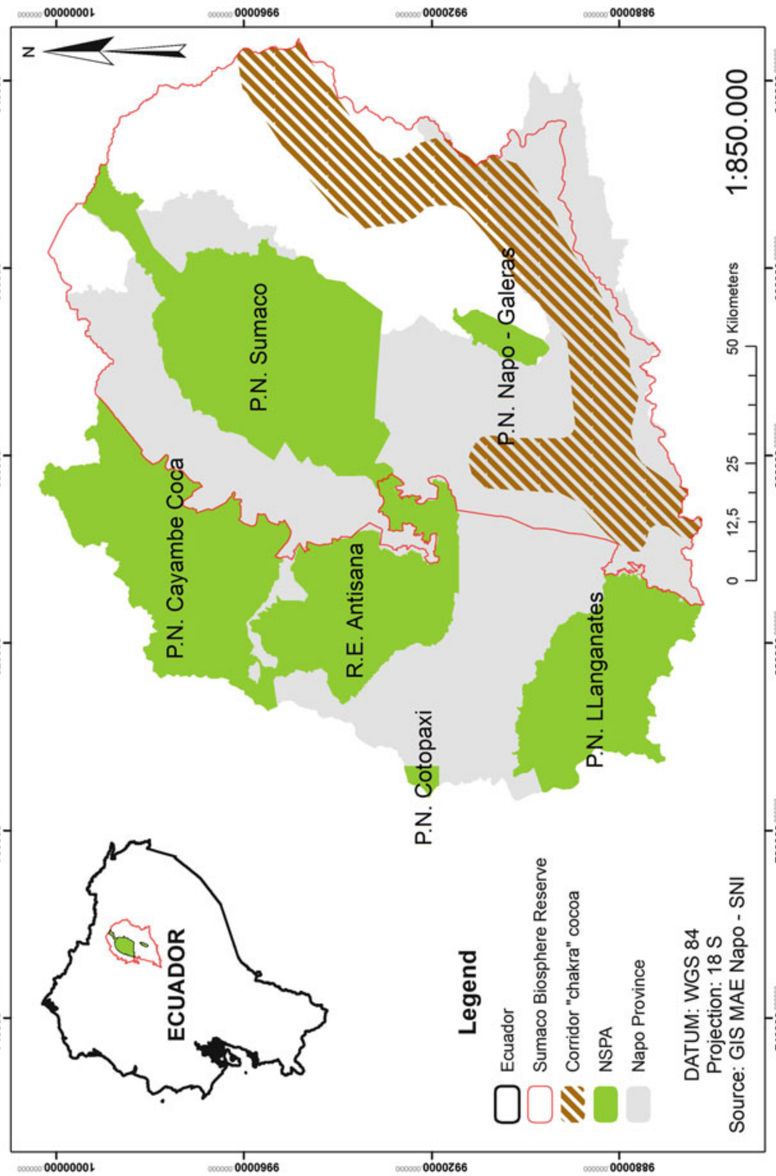

Fig. 1 Sumaco Biosphere Reserve and the chakra cacao corridor in Napo, Ecuador

integrates cultivation of staple food and medicinal plants, including manioc (*Manihot esculenta* Crantz), banana (*Musa paradisiaca* L.), peach palm (*Bactris gasipaes* Kunth), and other edible and medicinal plants that enable food and health security (Irvine 2000; Lu et al. 2004; Whitten and Whitten 2008). Over time, other agricultural species with commercial value have been integrated into this traditional agroforestry system, which is the case of the fine-flavored cacao (*Theobroma cacao* L.) and robusta coffee (*Coffea canephora* Pierre ex A. Froehner). The size of cultivation plots of cacao within an Amazonian chakra is in a range of 0.5–4 ha (Gizb 2011); these plots are generally located in remaining areas of primary and secondary forests and fallow land. This forms a landscape that resembles a mosaic economically productive and ecologically friendly to the biodiversity of the area.

The SBR contains near 12,500 ha of cacao cultivated in the chakra system, which are managed by 9,200 farmers, approximately (Gizb 2011). Most of it is located in buffer and transition areas of the SBR and Yasuní, within the so-called cacao corridor (see, Fig. 1), and belongs to indigenous Kichwa communities which, since the 1970s, had to adapt to the process of agricultural colonization and relocated their settlements in areas surrounding the Sumaco and Yasuni reserves. While the state has guaranteed the property rights of these communities through land titles and facilitated their access to agricultural credit (Irvine 1989, 2000; Perreault 2003), the intensive migration to the area observed in the last 40 years (Bilsborrow et al. 2004) has also implied diversification of local population and new forms of land use oriented not only to subsistence but also to the market. From an economic perspective, the integration of subsistence and commercial agriculture specialized in the market niche of fine cacao has implied the improvement of households' income. Ecologically, it has produced the effect of redrawing the northern Amazon landscape, pictured now as a multifunctional rainforest with productive plots of cacao or coffee, patches of primary and secondary forest, and stubble and non-used areas, all of which are needed for the soils' resilience in their multiple strata.

The cultural meaning of the chakra system for local population is directly related to the conservation of the Amazon landscape. Cultural practices among the SBR and Yasuní reserve include: selective classification of crops and identification of fertile or unfertile time periods based on the moon's phases, a particular local calendar, the fluorescence of some trees, the birds' incubation period or flight style, and/or some insects' behavior (Avilés and Sarmiento 1997). As suggested by Irvine (2000) and GIZ (2013), these practices have enabled indigenous local population to achieve a certain harmony between food security, income generation, and the preservation of traditional medicine and spiritual values.

Recently, new challenges that climate change presents to local population in the SBR have motivated research both on the capacity of the chakra system to facilitate the adaptation of local population and the rainforest ecosystems to climatic conditions and their capacity to contribute to climate change mitigation. While the former goes beyond the scope of this chapter, the latter is developed in detail in the following chapters.

Methodology

The research project "Diversification of land use and carbon assessment for biodiversity preservation," in its initial phase, studies changes in carbon storage, biodiversity preservation, and productivity in various land-use systems. The investigation was implemented in 2011 in the buffer and transition zone of the Sumaco Biosphere Reserve and aims at examining the potential for carbon storage by the chakra system, therefore assessing their potential for climate change mitigation. The project is located in the so-called cacao corridor in the province of Napo in the northeastern part of the Ecuadorian Amazon region. The research was performed as results of an international collaboration of universities including the Amazon State University (Universidad Estatal Amazónica) in Ecuador, the Tropical Agricultural Research and Higher Education Center (Centro Agronómico Tropical de Investigación y Enseñanza) in Costa Rica, and the Technical University of Munich in Germany.

The criteria used to select cultivation plots where traditional agroforestry practices are implemented (i.e., classification of plots under the chakra system) were percentage of shadow $\geq$10 %, net area of chakras $\geq$0.5 ha, and the farmers' willingness to support the system. Fifteen circular temporary plots of 1,600 m^2 under the chakra system were selected to measure the numbers and diversity of tree species and the amount of carbon captured in each plot and to assess the diversity of tree species and practices that produce food and medicinal plants. Similarly, 8 circular temporary plots under the monoculture system were also selected for the purpose of comparison. The cacao chakras included in the sample are, on average, 7 years old, have diversified shading systems in multiple strata and growth periods, and have the potential to store carbon efficiently each year. Table 1 summarizes the cultivation plots' characteristics.

In all temporary plots of 1,600 m^2, diameter at breast height (DBH) was measured (taken at 1.30 m) from all trees and palm with DBH $\geq$ 10 cm, and the total height was also measured. The floristic diversity of species was identified in situ, by using common and scientific names at the level of family, genus, and species. Species that were not recognized in situ were collected and identified in a national herbarium with the help of expert botanists.

Multiple systems of land use were selected in the lower area of the Sumaco Biosphere Reserve (Fig. 1), specifically in Tena and Archidona cantons within the Napo province. All sites are located below 700 m above sea level. The plots selected belong to farmers from the Kallari and Wiñak producer organizations, both members of the Cacao Dialog Table (MCFA in Spanish) in the SBR. Plots chosen for comparison in native forests were located in the Jatun Sacha Biological Station (EBJS).

Research on the contribution of the chakra system to climate change mitigation adopted the IPCC methodology for assessing the capacity of traditional agroforestry for carbon sequestration. This includes methods to estimate the amount of biomass and carbon in each one of the land-use systems.

According to the methodology used by Jadán et al. (2012), ground biomass was estimated using algometric equations formulated for primary rainforest species.

Table 1 Cultivation plots studied to assess the capacity of the chakra agroforestry system to conserve tree species diversity and carbon sequestration

Land-use system	Forest cover (%)	Years of agricultural use (average)	Sample (number of plots)	Surface (hectares)
Traditional agroforestry system (cacao chakra)	40.6	7	15	2.4
Cacao monoculture	4	5	8	1.3

Source: Torres et al. (2013)

Table 2 Algometric equations used to estimate the air biomass of trees in the shade areas of cacao plantations in the Sumaco Biosphere Reserve, Napo Province

Ecosystem or species	Equation	Range (dap, age)	R^2	Source
Tropical forests	$\text{Ln (Bt)} = -1.864 + 2.608 \times \text{Ln (dap)} + \text{Ln} (d)$	5–150	0.99	Chave et al. (2005)
Bactris gasipaes	$\text{Bt} = 0.74 \times \text{h}^2$		0.95	Szott et al. (1993)
Cacao	$\text{Bt} = 1.0408 \exp^{0.0736} \times {}^{(\text{d}_{30})}$		0.97	Ordóñez et al. (2011)
Low latizales (1–5 cm dap)	$\text{Bt} = 10^{(-1.27+2.2} \times {}^{\text{Log (dap))}}$	0.3–9.3	0.88	Andrade et al. (2008)
Musaceae	$\text{Bt} = (185.1209 + 881.9471 \times (\text{Log(h)/h}^2))/1000$			ANACAFE (2008)
Palmas in general	$\text{Bt} = 7.7 \times \text{h} + 4.5$		0.90	Frangi and Lugo (1984)
Roots	$\text{Br} = \exp(-1.0587 + 0.8836 \times \text{Ln Bt})$		0.84	Penman et al. (2003)

Notes: R^2 ajustado; *Bt* total biomass area (kg arbol^{-1}), *Br* underground biomass, *dap* diameter of breast length (cm), *d* basic density of the wood, d_{30} diameter taken from the bass at 30 cm, *h* total height (m), *exp* strength of the base e, *Ln* natural logarithm (base e).
Source: Based on Jadán et al. (2012)

These equations were also used to calculate low-latizal sapling biomass and necromass (Table 2). The underground biomass was calculated using the equation recommended by the IPCC (2003). The biomass of dead wood was calculated based on volumes obtained via the Smalian formula taken in different decomposition categories (Table 3).

The estimated biomass was converted into units of C by multiplying by the 0.5 factor of conversion, as indicated in IPCC (2003). The values obtained were expressed as MgCha^{-1} (mega grams of C per hectare).

The organic carbon in the soil was estimated using the percentage of organic C and the apparent density and deepness of the sample. The total amount of C that is stored was calculated, adding the C to each of the components of the ecosystem (biomass, necromass, and soils) in each one of the evaluated systems (Table 3).

Table 3 Equations used to calculate the underground biomass of different components evaluated in the Sumaco Biosphere Reserve, Napo Province

Component	Equation	Variable meaning	Source
Necromass		S1 = initial section	
Volume of dead wood	V = (S1 + S2)/2 *L	S2 = final section	
		L = length timber log	Schlegel et al. (2001)
Biomass of dead wood	B = V × Db	B = biomass (Mg)	
		V = volume (m^3)	
		Db = wood basic density (Mg m^{-3}) in the several decomposition categories proposed by IPCC (2003).	
Soil organic carbon	SC = CC × AD × P	SC = soil carbon (Mg C ha^{-1})	Schlegel et al. (2001)
		CC = content of carbon percentage	
		AD = apparent density (Mg cm^{-3}).	
		P = soil thickness in the sample (cm)	
Total carbon stored	TCS = CTB + CN + OCS	TCS = total stored carbon (Mg C ha^{-1})	
		CTB = carbon stored in the biomass (above and under the soil)	
		CN = carbon stored in the necromass	
		OCS = organic carbon in the soil	

Source: From Jadán et al. (2012)

The air biomass in tropical forests was estimated based on the wood density (d) of tree species with a DAP (diameter of breast length) greater than 10 cm through the equation formulated by the Global Wood Density Database (Zanne et al. 2009), i.e., Ln (Bt) = $-1.864 + 2.608 \times \text{Ln (DAP)} \times \text{Ln}\ (d)$.

Contribution of the Chakra Agroforestry System to Climate Change Mitigation

As reviewed in the Introduction, the benefits of agroforestry systems for carbon sequestration and climate change mitigation are nowadays widely recognized. Adequate management of these systems increases their potential for recovering part of the carbon released into the atmosphere due to deforestation in the world (Montagnini and Nair 2004). Therefore, agricultural production has the potential to be less a problem and more part of the solution to problems related to climate change and development (Hoffmann 2011).

Table 4 Average ± standard error for C stored in the traditional chakra cacao agroforestry system and in cacao monoculture, compared with carbon stored in primary rainforests evaluated in the cantons of Tena and Archidona, Sumaco Biosphere Reserve, Napo Province, 2011

Storage components (Mg C ha-1)	Primary rainforest	Cacao chakra agroforestry system	Cacao monoculture
C air biomass	206.2	52.8	5.7
	±29 a	±8.1 b	±2.5 e
C root biomass	58	15.3	1.8
	±7 a	±2 b	±0.8 d
C total biomass	**264.2**	**68**	**7.6**
	±36 a	±10.3 b	±3.2 de
C necromass	4	4.1	2.8
	±0.8 ab	±0.4 a	±0.6 abc
C organic soil	65.9	69.2	74.9
	±9.2 ab	±4.9 a	±6.8 a
Total carbon	**334.2**	**141.4**	**85.2**
	±41.7 a	±11.9 b	±7.9 c

Source: From Jadán et al. 2012

The initial findings of the project, reported in Table 4, show that, in comparison with primary rainforest, traditional agroforestry systems based on cacao farming store 42 % of C (334 Mg C ha^{-1}) and 56 Mg C ha^{-1} more than cacao monocultures (see, also, Torres et al. 2013).

The carbon content in air and root biomass shows that the cacao chakra system contains 896 % more C than cacao monocultures (68.1 Mg C ha-1 and 7.6 Mg C ha^{-1}, respectively). This high percentage of carbon storage in the chakra system corresponds to the diversity of trees used for timber, most of which have a high commercial value, for example, chuncho [C*edrelinga cateniformis* (Ducke) Ducke], cedro (*Cedrela odorata* L.), caoba (*Swietenia macrophylla* King), aguacatillo (*Persea* spp.), canelos (*Ocotea* spp.), guayacán [*Tabebuia chrysantha* (Jacq.) G. Nicholson], laurel [*Cordia alliodora* (Ruiz and Pav.) Oken], and pigüe [*Pollalesta discolor* (Kunth) Aristeg] (see Table 6). There is also a diversity of fruit trees, bushes, and palm trees that form part of the local population gastronomic culture.

These findings on stored carbon in air and root biomass in cacao chakras are similar to those obtained by Ordoñez et al. (2011) in locations near the area of our study within the SBR. They register (68.6 Mg C ha^{-1}) in chakra agroforestry systems with cacao trees that are 8 years old, on average (Table 5).

These results show that, given the amount of carbon stored both in air biomass and in root biomass in cacao, fruit, and timber trees, the potential of the traditional cacao chakra system to enter into the carbon market is important. Also, participation in the carbon market could help to maintain other components of the chakra system, which produce ecosystem services with no market value.

Table 5 Average C stored in cacao plantations using the traditional chakra agroforestry system with 2-, 4-, 8-, and 12-year-old trees, evaluated in the cantons of Tena and Archidona, Sumaco Biosphere Reserve, Napo Province

	Cacao plantations using the chakra system (age in years)			
Storage components (Mg C ha-1)	2	4	8	12
C air biomass in the cacao	2.15	5.00	14.63	27.17
C root biomass in the cacao	0.67	1.42	3.67	6.53
C total biomass in the cacao	**2.83**	**6.43**	**18.30**	**34.71**
C biomass in fruit and timber-yielding trees[a]	50.34	50.34	50.34	50.34
C total biomass in the cacao plus fruit and timber-yielding trees	**53.7**	**56.77**	**68.64**	**85.05**

Source: From Ordoñez et al. (2011)
[a]Constant value, calculated in 12-year-old cacao plantations

Contribution to the Conservation of Plant Species Diversity and the Amazon Landscape

One of the main characteristics of the chakra system is the floral diversity and density of timber-yielding species, which mostly regenerate naturally.

With regard to the floristic diversity at family, genus, and species levels, we found an average of eight families, nine genus, and nine species in the chakra system. Meanwhile, in cocoa monoculture farms, only one family, one gender, and two species were found (in average). These demonstrate the contribution of the chakra with cocoa production system to the conservation of floristic diversity of fruit and timber trees. In addition, having a variety of species, commonly used for food, medicine, energy drink, craft, spiritual rituals, and multipurpose materials (Table 7), also shows its potential to adapt to climate change.

In relation to density, the chakra system with cacao was found to have on average 170 timber and fruit trees with a diameter greater than or equal to 10 cm at breast height (DBH). Figure 2 shows the number of trees identified in line with the DAP ranking.

A particular pattern of spatial distribution of timber tree species and fruit trees could not be identified due to the absence of systematic practices for planting timber or fruit trees. These trees grow in a process of natural regeneration from the dispersion of seeds caused by wind or from the diversity of the fauna present in the system. As a general observation, it can be mentioned that timber-yielding trees can be found in distances between 15 and 20 m apart (Figs. 3, 4, and 5).

However, it is important to highlight that, at the time when producers engage in crop management, timber species of commercial value are generally carefully managed. The management of tree diversity in the chakra system (Table 6) shows how the Amazonian Kichwa population maintains crucial information about plant resources from a solid popular knowledge of plant species and their uses. Thus, it can be said that chakras are a model of biodiversity conservation; at the same time, they provide ecosystem services for the livelihoods of local population.

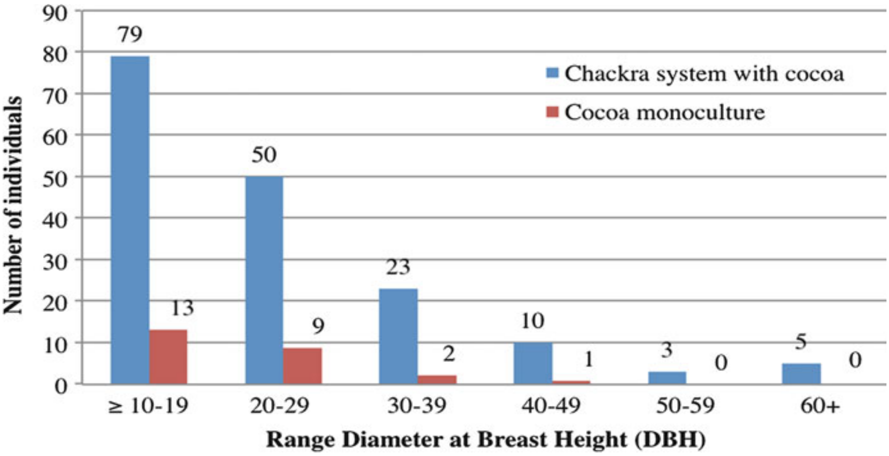

Fig. 2 Number of timber and fruit trees with DAP ≥10 cm

Fig. 3 Typical chakra system with cocoa plants in SBR, Napo, Ecuador (Photo: Bolier Torres_2013)

Contribution of Cacao Chakras to Food Security and Climate Change Adaptation

The effects of climate change on production systems are particular to each region. The number of extreme weather events, droughts, floods, and temperature rise affects agriculture, especially monocultures. Genetic diversity of production

Fig. 4 Woman harvesting cocoa beans in the chakra system in SBR, Napo, Ecuador (Photo: Thomas Müller_2010)

Fig. 5 Local farmers in a training workshop for estimating carbon sequestration in chakra system with cocoa in SBR, Napo, Ecuador (Photo: GIZ_2012)

Fig. 6 Parade members of the cacao round table – MCFA in the SBR, Napo, Ecuador (Photo: Mesa del Cacao RBS_2010)

Table 6 Main timber-yielding trees found in the traditional chakra system with cacao in the Sumaco Biosphere Reserve, Napo Province 2012

Species	Family	Local Name
Cordia alliodora (Ruiz and Pav.) Oken	Boraginaceae	Laurel
Cedrela odorata L.	Meliaceae	Cedro
Cedrelinga cateniformis (Ducke) Ducke	Mimosaceae	Seike, chuncho
Ceiba samauma (Mart.) K. Schum.	Bombacaceae	Ceibo
Myroxylon balsamum (L.) Harms	Fabaceae	Bálsamo
Cabralea canjerana (Vell.) Mart.	Meliaceae	Batea caspi
Capirona decorticans Spruce	Rubiaceae	Capirona
Minquartia guianensis Aubl.	Olacaceae	Guayacán
Tabebuia chrysantha (Jacq.) G. Nicholson	Bignoniaceae	Guayacán
Nectandra cissiflora Nees	Lauraceae	Canelo amarillo
Ocotea amazónica (Meisn.) Mez		
Swietenia macrophylla King	Meliaceae	Caoba
Clusia ducuoides Engl.	Clusiaceae	Pungara
Vochysia biloba Ducke	Vochysiaceae	Tamburo
Gustavia macarenensis Philipson	Lecythidaceae	Paso
Pollalesta discolor (Kunth) Aristeguieta	Asteraceae	Pigüe
Terminalia Amazonia (J.F.Gmel) Exell	Combretaceae	Roble Yumbingue
Otoba parvifolia (Markgr.) A.H. Gentry	Myristicaceae	Sangre de Gallina
Caryodendron orinocense H. Karst.	Euphorbiaceae	Maní de árbol

Source: This study 2013

systems with high diversity of plants and animals is a means to address climate change (Kotschi and von Lossau 2012).

In the Sumaco Biosphere Reserve, chakras are based on the cultivation of cacao, combined with fruit trees and food plants, which also have the function to store carbon during their growth process. This is the case of guabos (*Inga* spp.), grape tree (*Pourouma cecropiifolia* Mart.), hard chonta (*Bactris gasipaes* Kunth), white cacao (*Theobroma bicolor* Bonpl.), and introduced fruit trees such as achotillo (*Nephelium lappaceum*), cherimoya [*Rollinia mucosa* (Jacq.) Baill.], among others. Given that, at 2010, there were about 12,500 ha of cacao-based chakra farms in the SBR, managed by approximately 9,200 producers (Giza 2011), it can be said that the contribution of traditional agroforestry to climate change mitigation is important (see, also, section "Methodology").

Noteworthy, research supported by the German Development Cooperation (GIZ) on the contribution of traditional agroforestry to local economies suggests that the chakra system substantially supports rural livelihoods. Indeed, for producers from the Kallari Association in the SBR, it was found that 42 % of the household monetary income comes from the sale of cacao and 37 % corresponds to produce that contributes to food security, i.e., staple food produced and consumed in chakras (GIZb 2011).

Table 7 shows the main species of fruit trees, shrubs, and palms that are commonly found in a chakra. These species contribute both to carbon sequestration and storage and the preservation of local food culture. All species listed in the table correspond to the cacao-based chakras. Their botanical identification and most popular use were verified through two sources: de la Torre et al. (2008) and Ríos et al. (2007).

Edible plants found in chakras with cacao in the Sumaco Biosphere Reserve like banana (*Musa* spp.), cassava (*Manihot esculenta* Crantz), pineapple [*Ananas comosus* (L.) Merr.], corn (*Zea mays* L.), peanuts (*Arachis hypogaea* L.), lemongrass [*Cymbopogon citratus* (DC.) stapf], chili (*Capsicum annuum* L.), star peanut (*Plukenetia volubilis* L.), Chinese potato [*Colocasia esculenta* (L.) Schott], wild coriander (*Eryngium foetidum* L.), naranjilla (*Solanum quitoense* Lam.), and lemon (*Citrus* spp.) are among the 25 food species most consumed by 10 indigenous nationalities and one mestizo population, according to Ríos et al. (2007). This highlights that the chakra system, associated with a cash crop such as cacao, can be an option for carbon sequestration and climate change mitigation; it also contributes to food security. Chakras with cacao also can be integrated into wildlife corridors, connecting patches of primary or secondary forests while generating household income (Torres et al. 2013). Therefore, they potentially contribute to local populations' lifestyle in harmony with nature. However, more quantitative approaches are needed in order to develop concrete strategies for climate change adaptation.

Local Governance for Climate Change Management by Promoting Chakra System with Cacao

The Ecuadorian Constitution of 2008 includes two specific articles for climate change management: Article 413 ("The State shall promote energy efficiency, development and use of environmentally clean technologies, practices and policies as well as diversified renewable energy of low impact on and no risk for food

Table 7 Main species of fruit trees, bushes, and palms that store carbon and are used for consumption in chakras with cacao in the Sumaco Biosphere Reserve

Scientific name	Family	Common name		Use					
		Kichwa	Spanish	Comestible	Medicinal	Spiritual	Craft	Drink	Material
Bixa orellana L.	Bixaceae	Puka manturu	Achiote	x	x		x		x
Theobroma bicolor Humb. and Bonpl.	Sterculiaceae	Patas yura	Cacao blanco	x	x				
Grias neuberthii J.F. Macbr	Lecythidaceae	Pitun	Pitón	x	x				x
Ilex guayusa Loes	Aquifoliaceae	Waysa	Guayusa		x	x		x	x
Sanango racemosum (Ruiz and Pav.) Barringer	Grossulariaceae	Chiri waysa	Panka grande		x	x			
Gustavia macarenensis Philipson *Gustavia longifolia* Poepp. ex O. Berg	Lecythidaceae	Pasu	Paso	x	x				x
Pouteria caimito Radlk.	Sapotaceae	Tarpu aviyu	Caimito	x	x				x
Micropholis melinoniana Pierre *Micropholis venulosa* Pierre	Sapotaceae	Aviyu	Caimitillo	x	x				x
Artocarpus altilis (Parkinson) Fosberg	Moraceae	Paparawa	Frutipan	x	x				x
Brugmansia arbórea (L.) Lagerh	Solanaceae	Wantuk	Floripondio		x	x			
Persea americana Mill.	Lauraceae	Palta yura	Aguacate	x	x				x
Bactris gasipaes Kunth	Arecaceae	Chunta	Chonta duro	x	x		x	x	
Mauritia flexuosa L.f.	Arecaceae	Muriti	Morete	x		x	x	x	
Iriartea deltoidea Ruiz and Pav.	Arecaceae	Pushiwa	Pambil	x	x		x		x
Inga edulis Mart.	Fabaceae	Pakay	Guaba de bejuco	x	x				x
Pouroma spp.	Urticaceae	Pikuanka	Uva del monte	x				x	x
Annona cherimola Mill.	Annonaceae	Chirimoya	Chirimoya	x	x			x	x
Psidium guajava L.	Myrtaceae	Guayaba	Guayaba	x	x			x	x

Source: This study 2013

sovereignty, ecological balance of ecosystems and the right to water") and Article 414 ("The State shall take appropriate and transverse measures to mitigate climate change by limiting emissions of greenhouse gases, deforestation and air pollution"). This mandate is implemented through the National Development Plan for Good Living (2009–2013), in which objective 4 includes a policy to "promote the adaptation to and mitigation of climate variability with focus on climate change."

In 2008, both legal instruments set up a framework for the First Forum of Cacao, established in the city of Tena. This started an innovative process of land management of cacao fields based on strengthening a space of coordination (the cacao round table – MCFA) in the SBR (GIZa 2011). Such a public space includes participatory governance principles for issues regarding mitigation of and adaptation to climate change.

The SBR MCFA promotes the production of cacao on the basis of the chakra system. At the time this chapter was finished (August 2013), the MCFA had 41 actors representing the social, public, private, and cooperative sectors. Remarkably, 16 of them are representatives of local producers. The MCFA works with a concerted strategy called "faces of cacao"; this includes (Chacón et al 2012) (a) the agro-productive face, (b) the ecological face, (c) culture and tourism, and (d) flavors and smells. In this strategy, the ecological face addresses issues of climate change in chakras with cacao.

The MCFA is a local governance mechanism that helps to coordinate actions to mitigate climate change through the cultivation of cacao. It has achieved to promote participatory processes that address and guide a local agenda, where stakeholders, from public and private sectors, put in practice their ideas and interests in local action plans. These are implemented on the basis of a single driving scheme where all actors have the same rights to evaluate and decide on the principle of horizontality.

This model of management allows for particular and transparent contribution from each member of the MCFA platform to collective action. Participation draws on the principles of inclusion and interacting planning becomes practical action on the principle of complementarity. All these consolidate, in practice, the implementation of climate-smart, socially, and ecologically sustainable production systems.

Revival of the Amazonian traditional chakra system, adapted to a commercial produce that adds value such as cacao, has facilitated the political understanding of sustainability both on productive and climate change grounds. As a land management system, the Amazonian chakra is an example that shows how adaptation of production systems based on traditional knowledge can contribute to mitigate and adapt to climate change; therefore, it is useful for the promotion of sustainable production patterns in other areas where traditional systems also exist.

Conclusion

This chapter reports findings on the capacity of a traditional agroforestry system, called chakra, to contribute to climate change mitigation and adaptation. The focus was particularly on the integrative characteristic of such a system to harmoniously pursue the achievement of multiple goals. The findings suggest that chakras can be taken as examples of sustainable production that must be preserved in order to tackle climate change effects in tropical zones. Chakras with cacao in the Ecuadorian Amazon region provide diversified ecosystem services that can only be recuperated through the recognition of local knowledge. Furthermore, it is within the chakra system where decisions concerning harmonized landscapes, territory, and locally constructed processes of adaptation to climate change are made every day.

The findings can guide policy makers and other stakeholders in their decisions on land-use policy and measures to tackle poverty and climate change. In this way, the intention is to contribute to making future policies more effective, thus better enabling local population to strengthen their organizational capacity for climate change adaptation. Yet, encouraging dialogue platforms to support local governance mechanisms, based on sustainable production systems, requires transdisciplinary research focused on issues of sustainable climate change adaptation, that is, combining climatic concerns with "good living" goals. Further, it requires a development strategy that has the sustainable conservation of the rainforest as a main pillar and integrates local population in the Amazon region territorial planning.

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Part IV

Climate Change Adaptation Technologies

Build Sponge Eco-cities to Adapt Hydroclimatic Hazards

Chung-Ming Liu, Jui-Wen Chen, Ying-Shih Hsieh, Ming-Lone Liou, and Ting-Hao Chen

Contents

Abstract

Global population increases steadily and the majority are moving into cities. In the meantime, fast-growing cities are suffering with intensified hydroclimatic hazards. In this chapter, the authors propose to transform cities to sponge eco-cities so as to enhance their capacity on flood prevention, water resources replenishment, heat-island mitigation, biodiversity development, and air and water quality improvement. The strategy proposed is to replace all urban pavements with load-bearing, permeable, breathable, and sustainable pavements, so that rainwater will be stored underneath on raining days and water vapor will be released on sunny days. With water and air reaching soil underneath, underground ecosystem will flourish to enrich urban biodiversity. The JW eco-technology meets the seven criteria specified in this chapter to construct

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desired pavements. JW refers to the initials of the first name of the inventor, Jui-Wen Chen. These criteria are load-bearing capability, permeability, water storage capacity, breathability, underground ecosystem enrichability, affordability, and sustainability. In Taiwan, this JW eco-technology has been tested successfully for 10 years and is recommended by the official agency responsible for the green building certification. Certainly, it is not a trivial task to replace all man-made pavements of any city within a short period of time. A "Build Sponge Taiwan Initiative" has been launched by environmental groups in Taiwan to promote the idea to the general public and to hopefully build sponge eco-communities island-wide in the nearest future.

Keywords
Sponge eco-city • JW eco-technology • Urban-hydrological hazards

Introduction

Global population converges steadily into cities, and cities are expanding fast (UN 2012). Challenged by abnormal climatic events, record-breaking rainfall easily results in widespread floods in cities (Hibbs and Sharp 2012). A typical example was the devastating flood happened on July 21, 2012, in Beijing. Within a short period of time, many areas were buried in water with depths up to 2 m. Losses were severe. People are pondering how to avoid similar disasters in the future (Olesen 2012). Some experts on flood control suggest lifting the storm drainage standard from the current 1–3 years' recurrence period to a higher interval. However, with more extreme rainfall events are expected to occur (IPCC 2012), how much higher the recurrence interval should be raised? Besides, such strategy may not be affordable to all other cities (Searle 2004).

In the meantime, Beijing, with a population of 20 million living in a semiarid region, is hungry for more water resources. Overexploiting of groundwater with a yearly volume of 10 million is blamed for local land subsidence (Wang 2004). Therefore, storing record-breaking rainfalls for later usage may be more beneficial than diverting rainwater downstream for flood prevention. Such dilemma poses a profound challenge to all city governments. In addition, accelerated urban growth leads to intensified urban heat island (Lin and Yu 2005; Liu et al. 2007). Shortage of green zones and water worsen the condition and put stress on elderlies when unexpected heat waves prevail (Jenerette and Larsen 2006; Kovats 2008). Clearly, for a modern city, a balance between stormwater drainage (Butler and Davies 2010) and rainwater harvesting (Pandey et al. 2003) must be tackled respectably.

In this report, the authors propose to transform each city to a sponge eco-city, which is supposed to store rainwater during each rainfall event and to release water vapor on sunny days. Ideally, it is like a sponge absorbing and releasing water spontaneously. No mechanical or chemical or electrical energy is needed.

With enhanced detention capacity and extra water storage, a sponge eco-city can prevent flood and mitigate urban heat island smoothly.

How to create a sponge eco-city? The approach is to replace all man-made pavements with high load-bearing, high permeable, and high breathable pavements and to store rainwater within a gravel layer right below. With water and air reaching to the underground soil layer, tree roots and microorganisms will flourish underneath and pollutants captured will be decomposed and become nutrients to the ecological system (Liu et al. 2012; Fan et al. 2013).

Seven criteria are specified to select desired technique for paving the high load-bearing, high permeable, and high breathable pavement. Only the JW eco-technology (Chen 2004) meets these criteria and the completed pavement is named as the JW pavement. In the following, ideas about a sponge eco-city, the JW eco-technology, and the benefits accompanying with a sponge eco-city are explored.

Sponge Eco-city

The term "sponge city" was used by demographers in population studies to describe the fact that urban cities concentrate and absorb the surrounding rural populations like a sponge, resulting in a continuous, steady decrease in rural populations and a simultaneous expansion of urban areas (Budge 2006). However, urban development results in compactly built buildings, congested roads, traffic, pollutant accumulation, and the pooled consumption of a variety of materials, such as electricity, oil, food, water, and medicines (Van Rooijen et al. 2005; Grimm et al. 2008). Thus, while cities are very important for the development of modern human civilization, they also produce many problems, especially when they encounter hydroclimatic hazards (Hibbs and Sharp 2012).

In this report, a sponge city represents a city with all man-made pavements being replaced by permeable and breathable pavements which will store rainwater underneath and let water evaporate on sunny days. Since ecological system will flourish underneath, the authors name this kind of city as a sponge eco-city.

The idea of reducing effective impervious area in city so as to reduce surface runoff, thus reducing the amount of water directly entering the drainage system and increasing the retention time of rainwater in natural ecosystems to filter the surface impurities carried by rainwater, is proposed in the low-impact development (LID) strategy (Dietz 2007; USEPA 2000, 2006) and the sustainable urban drainage systems (SUDS) in UK (Ellis et al. 2002) and the water-sensitive urban design (WSUD) in Australia (Donofrio et al. 2009). In principle, concepts outlined in LID, SUDS, and WSUD are sound, but they are difficult to make an impact on either an ancient or a fast-growing city, such as Beijing. The key problem is lacking an innovative technology to pave a permeable, breathable, load-bearing, and sustainable pavement to replace all impervious man-made pavements with limited resources.

In the following, seven criteria are specified for identifying a qualified pavement technology:

1. Load-bearing capability: The compressive strength of the constructed pavement should reach 600 kg f/cm^2; that is, the pavement is with strength greater than 8,000 lb f/in^2 and is able to withstand the pressure from grinding by a heavy tank (Papagiannakis and Masad 2008).
2. Permeability: The pavement must be permeable to 10,000 mm/h of water under clean conditions and 1,000 mm/h when covered with leaves and dust (Scholz and Grabowiecki 2007). One advantage of such pavement is that no matter how strong a rainfall occurs, the surface runoff would be close to zero (Wu 2005). Thus, the construction of drainage ditches around the pavement may be unnecessary.
3. Water storage capacity: In many areas, it is specified that permeable pavements must be accompanied with gravel layers underneath (Krueger and Smitha 2012). The purposes are for stormwater detention and pollutant filtering (Sansalone et al. 2008). Since the environmental condition of each city is different, the designated water detention amount can be different. In this chapter, an effective 10-cm water storage layer is proposed, which can be achieved with a 33.4-cm-depth gravel layer of porosity 0.3 or in any other combinations of gravels and water-storing materials. Then, as the road area in Beijing is 62.7 Mm^2 (BSIN 2013), thus 6.27 Mm^3 of water, or 6.27 MT of water, could be stored underneath.
4. Breathability: Detectable movement of air flowing freely up and down through the pavement is specified. The purpose is to cool the ambient air through vaporing the underground water and to absorb air pollutants substantially into layers below the pavement (Liu et al. 2012). Also, the air provides necessary nutrients and active agents to the ecosystem underneath (Paul 2007).
5. Underground ecosystem enrichability: With air and water flowing freely into layers below the pavement, tree roots and microorganisms will flourish. Such underground ecosystem development is not detectable with eyes, which is in contrast to the ecosystem linked with the urban green landscape, but will function similarly, i.e., to decompose pollutants absorbed and clean the environment (Chapelle 2000; Liu et al. 2012). Such system may be named as an underground wetland (Mitsch and Gosselink 2007).
6. Affordability: This is an important factor to consider when transforming an ancient city in the third world to a sponge eco-city. The construction cost should not be a burden; the maintenance spending must be negligible; and, most importantly, there are minimized needs to repair or replace the pavement for a long period of time, such as more than 30 years. Therefore, when estimating the total budget for a period of 30 years or more, the cost will be affordable to almost all cities in the world.
7. Sustainability: With suitable maintenance being applied, major characteristics of the pavement, such as smoothness, evenness, load-bearing, permeability, water storage, breathability, and underground ecosystem development, must be kept for a period of 30 years or more. Thus, a considerable amount of resources and funding involved in replacing the pavement could be saved in the long run. These all meet the specification as a sustainable pavement (Gopalakrishnan 2011).

The JW Eco-technology

To every place explored by man, there must be a road. Under every road built by man, there must be an interruption of soil linking with nature. Therefore, all man-made pavements, such as walkways, road, etc., can be viewed as the first act of destruction by humans to the environment. Taking human skin as an example, if covered by paints, the skin would be deteriorated to a deceased condition. Hence, humans are practically living above deceased Earth surface with man-made pavements extending widely all over a city and are wishing that all urban-hydrological problems can be managed through engineering measures, which is clearly an impossible mission. To sustain urban environment, pores of all man-made pavements must be opened up so as to cooperate with Earth while facing the challenge of long-lasting heat waves, severe droughts, devastating floods, etc.

The pavement paved with the JW eco-technology (Fig. 1) is characterized with a specific thickness of gravels under a concrete pavement, which uses structured plastic frames with hydraulic conductivity (Liu et al. 2012), named as the JW aqueduct frame (Fig. 2), to replace traditional reinforced steels to ensure the compressive strength and flexural strength of the concrete pavement (Chen 2004). The JW aqueduct frame has a covering stripe which is removed after the solidification of concrete, so as to reveal holes of water pipes. These holes are named as pores of the JW pavement.

Since reinforced steels would oxidize, rust, and expand upon contact with water, efforts are needed to block water entry below the conventional reinforced concrete

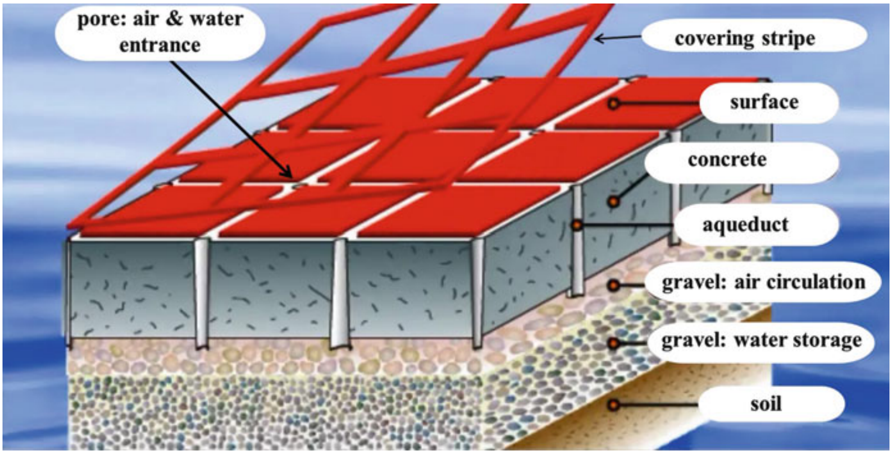

Fig. 1 Illustration of the JW pavement. The upper section is a rigid concrete block with the concrete being reinforced by the JW aqueduct frame (Fig. 2). Covering stripe of the aqueduct frame is removed after the solidification of concrete, so as to reveal holes of all aqueducts. These holes are named as pores of the JW pavement. Water and air are flowing freely through aqueducts. Below, gravels function as pillars to maintain the stability of the upper solid block, while the upper gravel layer facilitates air circulation and the lower gravel layer is for water storage

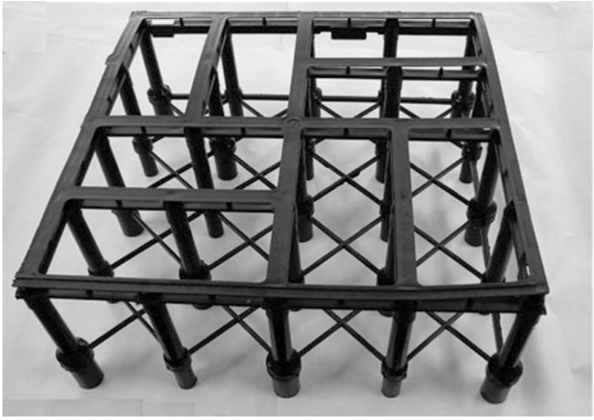

Fig. 2 The JW aqueduct frame

pavement (Papagiannakis and Masad 2008). In contrast, with the JW aqueduct frame, water is welcomed to flow freely into layers below. Furthermore, a conventional rigid pavement would crack with rainwater seeping underneath or tree roots extending below (Papagiannakis and Masad 2008). This is not the case with the JW pavement.

In Taiwan, a 50-meter length JW road was constructed within the campus of the Taipei National University of Technology (TNUT) since 2003, with tree roots unblocked along the pavement. Until now, the road maintains similar functions with no crack or bumps (Tsai JH, 2010, Long-term monitoring of the pervious pavements in front of the architecture building of the National Taipei University of Technology, personal communication. (in Chinese)). Liu et al. (2012) and Fan et al. (2013) opened up portion of this pavement and revealed that tree roots were growing widely underneath. In Taiwan, a 10-year guarantee for the evenness and smoothness of the JW pavement is provided by the inventor. Theoretically, if damages caused by earthquake would not happen, the JW pavement could last for more than 30 years and hence qualify as a sustainable concrete pavement (Van Dam et al. 2012).

The JW plastic frame composes of many air-cycle aqueducts (Fig. 2). On the surface, it is about 100 pores per square of meter, acting as skin holes for allowing the flow of rainwater and air circulation. In comparison to the conventional porous asphalt pavement, grass bricks, and permeable tiles, negligible surface runoff can be measured over the JW pavement during each rainfall event (Wu 2005), for the rainwater penetrates directly through each aqueduct into the lower gravel layer (Fig. 1) rather than slowly seeping through the pavement as most other permeable materials.

Tests done by Li (2004) showed that when all the aqueduct entrances were free from dusts and leafs, the pavement had an average infiltration rate of 12,557 mm/h; if occupied thoroughly by dusts and leafs, it still recorded an average infiltration rate of 1,487 mm/h. Still, routine maintenance is recommended to keep the aqueducts free from clogs and maintain a good condition. In Taiwan, the Architecture and Building Research Institute recommends the usage of the JW pavement in the green building evaluation manual and specifies the porosity below the JW pavement as 0.3, which is about six times of those conventional permeable tiles sold in Taiwan (Lin et al. 2012).

The mission and bearing load of each man-made pavement is designed differently; therefore, the underlying depth of the gravel layer, the thickness of the concrete pavement (i.e., the length of the air-cycle aqueduct), the artistic surface treatment, etc., can all be different. For instance, the thickness of a road pavement must be larger than that of a walkway. In short, the thicker the concrete pavement, the more weight the pavement can bear.

Li (2004) measured the vertical point load on a JW concrete block with a thickness of $60 \times 60 \times 7.5$ cm by the test specifications for flat-panel concrete given by the European Federation for Specialist Construction Chemicals and Concrete Systems (EFNARC). The authors found that the block could withstand 20–30 kg/cm^2 (equivalent to 300–420 psi), while the standard load of a general large vehicle is 90 psi. Pavements with thicknesses of 10 cm and 15 cm could withstand 30–40 kg/cm^2 and 40–60 kg/cm^2, respectively. Acceptable ductility, malleability, and toughness of the JW concrete block were also noted. In addition, according to the standard specification CNS1232 of Taiwan, the compressive strength of JW pavement could reach 1,980 kg f/cm^2; according to the standard specification CNS1011 of Taiwan, the tensile strength of JW pavement reached 74 kg f/cm^2; according to the standard specification CNS10757 of Taiwan, the wear resistance of JW pavement reached 0.51–1.22 %; according to the standard specification CNS6471 of Taiwan, soluble sulfate only affected the JW pavement by 0.38 ± 0.01; according to the standard specification ASTMC979 of Taiwan, alkaline substances would not affect the surface characteristics of the pavement.

Meanwhile, the gravel layer can be specified with a longer depth for regions wishing to store more water. Or permeable pipes can be placed within the gravel layer to direct rainwater into the underground stormwater drainage system, as shown in Fig. 3.

In Taiwan, a 4×120 m JW road was recently constructed in Xizhi, New Taipei City, with two parallel underground water tanks capable of storing 70 t of rainwater. Measurements on April 18, 2013 show that around noontime the ambient temperature was about 33 °C, while the surface temperature of the JW road and the nearby asphalt road was about 26.2 °C and 38.2 °C, respectively. On August 12, 2013, the noontime air temperature was about 38.3 °C, while the surface temperature of the JW road and the nearby asphalt road was about 41.8 °C and 63 °C, respectively. With the pavement breathability, the surface temperature of the JW road is clearly much lower than that of the asphalt road. Furthermore, it is due to a significant amount of rainwater stored underneath in spring that the surface temperature of the JW pavement was lower than that of the ambient air (Chen et al. 2013).

Fan et al. (2013) compared the ecological activities below the JW pavement installed in TNUT with those under three other adjacent permeable pavements by collecting samples in the gravel and soil layers underneath and concluded that the microbial compositions and their activities under the JW pavement were both

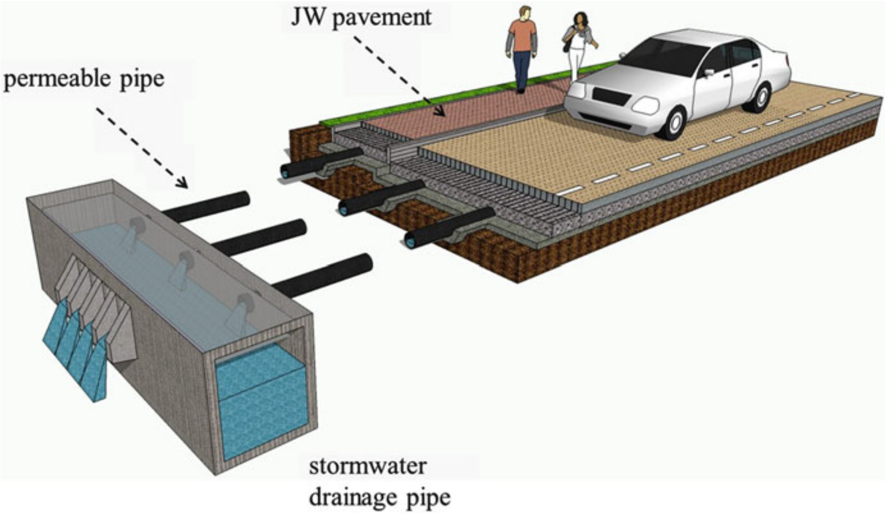

Fig. 3 Underneath the JW pavement, permeable pipes within the gravel layer can direct rainwater into the stormwater drainage system

superior to those under other pervious pavements. Bacterial communities under the JW pavement were more abundant and diverse. The soil under the JW pavement also reflected more activated and versatile microbial activities in all substrates and for specific types of functional guilds.

Liu et al. (2012) also studied the function of the JW pavement in TNUT and designed experiments to compare the variation of the air pollutants concentrations within a fenced area over the JW pavement with one vehicle emissions discharging into with results from similar experiments over a non-JW pavement. Under stagnant condition, it was found that the JW pavement diluted vehicle pollutant emissions near the ground surface by 40–87 % within 5 min of emission, while the data at 2 m height suggested that about 58–97 % of pollutants were trapped underneath the pavement 20 min after emission. Those quantitative estimations may be off by ± 10 %, if errors in emissions and measurements were considered. SO_2 and CO_2 underwent the most significant reduction. Very likely, pollutants were forced to move underneath due to the special design of the JW pavement. In order to track the fate of pollutants, parts of the pavement were removed to reveal a micro-version of wetland underneath (Fan et al. 2013), which could possibly hold the responsibility of absorbing and decomposing pollutants to forms harmless to the environment and human health.

According to the "2012 Yearly Parliamentary Validation of the Budget Price for Engineering Projects" of the Taipei City Government (TCG 2012), the JW permeable pavement has a unit installation price close to that of highly compressed bricks which is about 30 % lower than that of permeable tiles. But the compressed bricks require 21 times more than the JW pavement for the maintenance cost, which is mostly for replacing broken bricks every year. Also, the former is officially recommended to be replaced in every 5 years, while the latter has a life expectancy more than 30 years. In reality, local government would replace the former in every 10 years and pay more on the yearly maintenance. Therefore, with the JW pavement, the total budget would be at least 3–7 times lower than that using the highly compressed within a 30-year time span or 5–10 times lower than that of permeable tiles.

To all cities in the world, the JW aqueduct frame can be manufactured locally, while materials such as concrete and gravels are from local origin and the construction workers are trained local labors. Under the principle of "everything local" and with a sustainable nature, paving of the JW pavement is absolutely affordable to all cities in the world.

In all, this section explains how the JW eco-technology meets the seven criteria specified for constructing a sponge eco-city: load-bearing, permeable, water-storing, breathable, underground ecosystem friendly, affordable, and sustainable.

Benefits of a Sponge Eco-city

What are the benefits of a sponge eco-city? In the following, a few cities are selected for illustration.

Using Beijing as an example, given that 10 % of the 3,377 km^2 of the developed areas (337.7 million m^2) (BSIN 2012) are sidewalks, squares, and parking lots with 62.7 million m^2 of road areas, there are approximately a total of 400 million m^2 of man-made pavement that can be changed to the JW pavement. If the space under the pavement is designed to store 10-cm effective thickness of rainwater, approximately 40 MT of water can be stored, which is equivalent to 80 streams of the Cheonggyecheon in Seoul, Korea. Here the Cheonggyecheon is selected for comparison due to it being a successful urban renovation project. The Cheonggyecheon was once covered with an intra-urban double-deck highway and the ambient air temperature of the area was about 5° higher than that of the central area. In early 2000s, a nature restoration project was executed and the stream with approximately 500 KT of water storage was restored (Cho 2010). The ambient temperature of the area is now about 3.6° lower than that of the central area (RESTORE 2013).

If one restored Cheonggyecheon-type stream is enough to cool the nearby area by 8.6° with respect to the previous covered condition, a weakened urban heat island could be expected in Beijing with 80 streams of Cheonggyecheon flowing underneath. With such detention capacity, the chance to observe serious flooding in Beijing would be lowered. Moreover, future record-breaking rainfalls will be kept to replenish local water resources. There are other unexpected benefits: every degree of the ambient temperature lowered will lead to less air-conditioning demands and hence less energy consumed and less carbon dioxide and air pollutants emitted from power plants (Kan and Tien 2004). Also, at least 50 % of carbon dioxide and air pollutants emitted by vehicles will be captured by the JW road to become nutrients for the underground ecological system (Liu et al. 2012). Clearly, reduction of ambient PM2.5 level and haze could be expected and hence the public health risk would be lowered considerably (Liu et al. 2013).

The benefits to create a sponge eco-city are impressive. If 10 % of the following urban areas, London (1,623 km^2), Paris (2,844 km^2), Berlin (1,347 km^2), Moscow (4,403 km^2), Warsaw (544 km^2), Cairo (1,709 km^2), Istanbul (1,399 km^2), Delhi (1,943 km^2), Bangkok (2,331 km^2), Shanghai (3,497 km^2), Tokyo (8,547 km^2), Los Angeles (6,299 km^2), Houston (4,644 km^2), Rio de Janeiro (2,020 km^2), Buenos Aires (2,642 km^2), and Sydney (2,031 km^2) (DEMOGRAPHIA 2013), are man-made pavements and can be converted to the JW pavements with a designated 10-cm effective depth of rainwater storage, then about 16, 28, 14, 44, 5.4, 17, 14, 19, 23, 35, 86, 63, 46, 20, 26, and 20 MT of water can be stored, respectively, which is equivalent to 32, 56, 28, 88, 10, 34, 28, 38, 46, 70, 172, 126, 92, 40, 52, and 40 Cheonggyecheon streams, respectively. The benefits to all these cities with such a tremendous amount of detention capacity are astonishing. Although the exercise here only provides a rough idea of the potential in changing these cities to sponge eco-cities, it gives a hope to sustain these cities and other expanding urban areas to adapt hydroclimatic hazards under the ongoing climate change.

Discussion and Conclusion

This chapter proposes a daring and innovative idea: transform urban cities to sponge eco-cities by replacing all man-made pavements to load-bearing, permeable, water-storing, breathable, underground ecosystem flourishing, and sustainable pavements. The goal is to store rainwater below the urban pavements on raining days and to release water vapor on sunny days. It will function as a sponge spontaneously with no extra efforts needed. Benefits include enhancing the detention capacity and hence strengthening local flood prevention capability, storing rainwater to replenish local water resources, cooling pavement temperature and mitigating urban heat island, nursing the development of the underground ecosystem, capturing vehicle-emitted pollutants and CO_2 to clean the ambient environment, filtering stormwater pollutants, reducing haze and public health risks, saving long-term costs on pavement replacement, and adapting hydroclimatic hazards and climate change.

As global population is growing steadily and congesting restlessly into cities, they are becoming the most vulnerable areas in facing hydroclimatic hazards (Mitchell 1999; Pelling 2003). Transforming cities to sponge eco-cities will lower this risk and, therefore, is the most favorable approach toward sustainability. It is worthwhile to note that the transformation toward sponge eco-cities has no conflict with the installation of the current urban stormwater drainage system (Butler and Davies 2010). Rather, the combination will surely enhance the local water storage and the detention and drainage capacity (Sansalone et al. 2008), as shown in Fig. 2. The idea has already been exercised in Taiwan (Chen et al. 2013).

In this chapter, seven criteria are specified for identifying the suitable technology: load-bearing capability, permeability, water storage capacity, breathability, underground ecosystem enrichability, affordability, and sustainability. Among them, affordability is the most important factor for cities in the third world, i.e., low costs in installation, maintenance, and replacement for at least 30 years or more. In this chapter, the JW eco-technology is recommended for fulfilling those seven criteria with supporting experimental data outlined. This technology has been tested in Taiwan for 10 years and is now recommended in the Taiwan green building evaluation manual (Lin et al. 2012) and is certainly ready to be tested and implemented in any place in the world.

Certainly, it is not a trivial task to replace all man-made pavements to the JW pavements within a short period of time; but for reducing the urban vulnerability and for sustaining nature and human population, it is better to start the task as early as possible. In Taiwan, a "Build Sponge Taiwan Initiative" (Liu and Hsieh 2013) has been launched by environmental groups to promote the idea to the general public. To create JW sponge eco-cities may be a dream difficult to fulfill, but it is possible to construct sponge eco-communities at every place in the nearest future. Hopefully, similar activities will be launched soon all over the world.

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Climate Change Adaptation Through Grassroots Responses: Learning from the "Aila" Affected Coastal Settlement of Gabura, Bangladesh

A. F. M. Ashraful Alam, Rumana Asad, and Afroza Parvin

Contents

Abstract

The southwestern coastal region of Bangladesh has faced thirty large- and moderate-scale natural disasters since the last two decades. Aila, the extreme disaster event, has unveiled major shortfall in the approach of conventional disaster preparedness. Gap between planned intervention and the way coastal inhabitants respond to climatic exposures has widened due to lack of understanding of the grassroots risk perception and effectiveness of associated responses

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from them. The research examines locally adopted measures taken for disaster risk mitigation in the coastal settlements of Gabura, Bangladesh, and recommends future directions for climate change adaptation. As grassroots responses, firstly, the age-old spontaneous coping mechanisms of the individual households with particular emphasis on their baseline vulnerability were explored. Secondly, the nonphysical and physical responses before, during, and after disaster were categorized. Finally, with a strength and weakness matrix, the effectiveness and limitations of grassroots responses related to typical exposures and extremes were pinpointed. The study concludes that grassroots responses are mostly effective as adaptive measures during typical hazards; however, they have limitations in extreme events. Most importantly, adequate recognition of grassroots responses will not only inform better adaptation but also contribute to broader regional development planning and climate change policy context.

Keywords

Climate change adaptation • Grassroots responses • Baseline vulnerability • Coastal settlements

Introduction

Bangladesh is globally considered one of the most vulnerable countries to sea level rise.[1] This is obvious for its very low elevation geographical setting with a flat deltaic topography exposed to extreme climate variability. The coastal settlements comprise 32 % of the country's total area.[2] Nearly seven million households are exposed to frequent storm surge and cyclones.[3] According to (Parry et al. 2007), with a one meter sea level rise, about 20 % of the country will be not only inundated with saline water but also the poor and marginal groups will be critically affected (Rahman et al. 2007). Apart from the anticipations concerning climate change, the region remains vulnerable due to large population size, low economic strength, inadequate infrastructure, and chronic inefficiency with institutional capacity (MoEF 2005, 2009 World Bank 2010).

Post-disaster experience[4] in recent years unveiled shortfalls in the approach of government-led disaster preparedness. NAPA (MoEF 2005) and BCCSAP (MoEF 2009) have been criticized as top-down and unable to recognize the role of community in the process. Gap between the conventionally advocated adaptation strategies and the way coastal grassroots respond to hazard consequences has

[1]World Bank (2010, 2013) recognizes Bangladesh the third most vulnerable country to sea level rise and it will be worsening with an expected 2 °C rise in the world's average temperature in the next decades.

[2]The coastal settlements cover an area of 47,211 km^2.

[3]Coastal settlements in Bangladesh receive 40 % of the impact of total storm surges in the world (Dasgupta et al. 2010).

[4]Category-1 cyclone "Sidr" in 2007 and "Aila" in 2009

widened due to inadequate knowledge of associated risks and vulnerability. To date, attempts to recognize the role of grassroots responses in climate change adaptation of coastal settlements are scanty and, therefore, could not be effectively included in government's policy responses, except Parvin and Cassidy (2012), who recently examined the role of indigenous knowledge towards resilient coastal settlement planning.

This chapter investigates in Gabura, one of the most disaster-prone settlements in the southwestern coastal region of Bangladesh that was hit by the deadly cyclone "Aila" in 2009. The research explores the individuals' survival responses inherent in grassroots lifestyle before, during, and after disaster. Underpinned with an analytical framework for vulnerability, grassroots responses, and adaptation, it examines the effectiveness of individuals' responses during typical and extreme hazard events. Finally, insights on how to mainstream grassroots responses into the process of climate change adaptation have been given.

Analytical Framework for Vulnerability, Grassroots Responses, and Adaptation

During exposure to a given hazard, individual responds in various degrees. Based on the severity of disaster, the effectiveness of responses is quantified. As the human being's responses to a hazard are based on his social, political, and economic conditions, there is an increasing recognition that disasters including the components of vulnerability, adaptation, and resilience are socially constructed (Cannon and Müller-Mahn 2010). To understand the effectiveness of grassroots responses in the coastal settlements of Gabura, which is the aim of this chapter, an analytical framework has been proposed. The framework defines baseline vulnerability of the coastal grassroots instigating responses.

Climatic and Non-climatic Vulnerability of the Coastal Settlement

The coastal settlements of Bangladesh are witnessing a number of climatic impacts, i.e., frequent flood, erosion of the coastline, rising water tables, long-term inundation, saltwater intrusion, and other biophysical effects.[5] These are proxy for social vulnerability in sectors concerning water resources, agriculture, human health, fisheries, tourism, and above all the human settlements of the coast itself (Klein and Nicholls 1999). On top of the anticipated and observed climate change-induced

[5]In Bangladesh, the floodplains of the lower Ganges and the Surma basins became exceedingly vulnerable (Alam et al. 1999). Elevated riverbeds due to continued sedimentation induced backwater effect, which eventually increased both the frequency and severity of floods (Huq et al. 1996). Increased magnitude of cyclonic storm surges inundated the coastal unprotected lands with saline water (Islam et al. 1998). The forest ecosystem of the resourceful Sundarbans has been disturbed by floods in monsoon and moisture stress in winter (Ahmed et al. 1999).

risks, the settlements face high level of threats caused by various non-climatic factors. The coastal grassroots suffer from unequal distribution of resources and welfare incentives compared to those in the rest of the country. Even the existing institutional structures are not favorable to ease the hardship of people through providing minimum level of support, which translates into accelerated economic difficulties and social deprivation. Interestingly, the coastal settlements contain twofold characteristics in themselves, because, at one hand, they possess visible disparities triggered by the formal institutional channel coupled with climatic impacts and, all at once, are affluent in natural resources and biodiversity to offer varying livelihood opportunities, which assist people to adapt and retain there for centuries.

Scholars claim that deprivation of resources induces non-climatic vulnerability to individuals and societies in the form of poverty and marginalization (Adger and Kelly 1999; Hewitt 1983, 1997; Watts and Bohle 1993). These may refer to economic resources, technology, information, skills, infrastructure, institutions, and equity. They are often termed "generic determinants" of adaptive capacity of the social system (Brooks et al. 2005, p. 153), often specified by the political economy of the context that determine the sensitivity of the system to climate change. They constrain endogenous factors (i.e., the characteristics and behavior of the community) of coping responses (Cannon 1994). In this sense, vulnerability of the grassroots in coastal settlements is likely to have climatic and non-climatic differentiations and they are mutually inclusive. Irrespective of hazard circumstances, individual's accessibility and reliance on resources determine the first layer of vulnerability. In fact, the degree of accessibility determines the baseline status of the individual.

Baseline Vulnerability

The most widely accepted meaning of vulnerability has been defined as the "susceptibility of exposure to harmful stresses" and "the ability to respond" to those stresses (Adger 2006; Adger et al. 2007; Bohle et al. 1994; Kelman and Lewis 2005; Lewis 1999). Vulnerability, according to the IPCC definition (Houghton et al. 2001; McCarthy et al. 2001), includes "exposure" of a system as an external dimension to climate variations (Few 2003), as well as an internal dimension of its "sensitivity" and its "adaptive capacity." The two sets of definitions have some commonality within them – where "susceptibility" counterparts "sensitivity" of the later definition and "the ability to respond" resembles to the "adaptive capacity." It is to be noted that sensitivity is reliant on the baseline characteristics (climatic and non-climatic) induced by the whole (natural and social) system as discussed in the preceding segment, whereas adaptive capacity links more to the individual's willingness, understanding of priorities, and ability to perform in the system.

As exposure and climatic variability vary across contexts, vulnerability has geographical dimension (Lewis and Kelman 2010) and links to specific hazards and the likely exposure to hazard impacts (Brooks et al. 2005). A settlement having shelters made of permanent materials may not be that much susceptible to windstorm compared to those with temporary structures. Along this line, Lewis (1999) and Wisner et al. (2004) suggested that any kind of vulnerability assessment would focus on the susceptibility of concerned variables that characterize the well-being of people and, in other words, the root causes of sensitivity to a specific disaster and setting. While the social interpretations of disaster are not new (Burton 1993; O'Keefe et al. 1976), whatever their cause, their effects are perpetually rooted in societal processes that render certain groups or individuals particularly vulnerable to the impacts (Wisner et al. 2004) and over time (Uitto 1998).

However, the term vulnerability has become highly contested due to lack of precision (Cannon 2008b). It is often confused with poverty, marginalization, or any other conceptualizations that recognize sections of the disadvantaged population (Wisner et al. 2004). In order to comprehend vulnerability, it is clearly not adequate to understand only the types of hazards and the natural system themselves, but the hazard impacts on groups of people who are at different level of preparedness with varying capacities to recover. Therefore, the research employed a simple working definition from Wisner et al. (2004, p. 11), where vulnerability was meant as the "characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard." The definition implies that in order to understand the grassroots responses, it is important to identify the characteristics and condition of individuals in the community.

Cannon demonstrated conditions of social vulnerability as root causes of an individual that include one's initial well-being, livelihood and resilience, self-protection, social protection, and social and political networks including institutions (Cannon 2008a; Cannon et al. 2003). Others identify factors that hinder capacity of individuals as economic imbalances, disparity in power and knowledge among social groups, and inequality in welfare and social protection (Adger and Kelly 1999; Blaikie et al. 1994; Dow 1992). However, individuals' vulnerabilities change over time through changes in one's institutional and economic position (direct) and condition of shelter, food, and health (indirect); and these changes are affected by environmental changes (Adger 1999). In the present research, they have been termed as baseline parameters of vulnerability. Together they determine individual's instinct, relying on which one starts to respond to a given disaster event either normal or extreme. These parameters have been further illustrated as livelihood, food and health, education, kinship, and shelter as being considered the basic survival tectonics for an individual to constitute his/her household.

Among the five parameters, livelihood (diversity of jobs, income and savings, assets), education (access to knowledge), and kinship (at neighborhood level, family and community) are independent although some may defy that livelihood and education depend on each other. It is true that certain livelihood opportunities are quasi-independent due to educational qualification remains as prerequisite to access them. However, in an underdeveloped and natural resource-based setting, livelihood opportunities are naturally in place. The component of access to education may not only rely on income than willingness and awareness to be literate based on the level of subsidy from government, whereas livelihood opportunity is central to establish individual's command over economic performances and resources to satisfy fundamental needs. Security of food and health (sources and supply of basic nutrients including safe drinking water) and decision of shelter (settlement, built environment, build form, natural resources/vegetation) are dependent variables as they are highly relied on individual's income, educational attainment, and network of kinship.

Nevertheless, it is to be noted that the parameters of baseline vulnerability do not necessarily constitute resilience, but determine the capacity to some extent to adapt to climate change scenarios. An important point also to be noted is that the main difference between baseline vulnerability and vulnerability definition is therefore the first one is a more intimate assessment of individual's ability than the society as a whole. Therefore, the parameters remain as the first-stage manual to assist individual households to analyze risk and prioritize allocation of resources to reduce immediate vulnerability arising from the household core.

Grassroots Responses in Climate Change Adaptation Process

Recognition of grassroots responses, the aim of this research, requires a clear understanding of the grassroots first. The verbatim "grassroots" encompasses the common and ordinary people at a local level rather than at the center of any major political affiliation or social organizations. Grassroots responses in this chapter limit themselves to those simple individual household-level coping strategies in face of continuing hazard exposures and are not subject to any planned intervention except from the grassroots community itself. Obviously, the grassroots coping strategies are hereditary in nature and central to the assumption that "an event will follow a familiar pattern and that previous coping actions are a reasonable guide for similar events" (Wisner et al. 2004, p. 320). It is the "learning by doing" evolution which makes use of indigenous knowledge gained over centuries. The indigenous knowledge is constituted through gathering of social memory of past weather extremes (Harley 2003). Strauss and Orlove (2003) refer to such practices as use of "intuitive data" derived from individual perception of recent experience of weather guided by historical weather data. Since data are always context specific, grassroots responses are highly localized, generating community-wide ownership and commitment (Jabeen et al. 2010, p. 418).

Parvin and Johnson (2012) identified that indigenous knowledge-based responses occur through stages of anticipation, coping, adaptation, and recovery. Based on their timing, grassroots responses can also be referred to craft passive (concurrent), reactive (responsive or ex post), and anticipatory (proactive or ex ante) (Fankhauser et al. 1999; Smit et al. 2000) "adjustments" (Brooks 2003; Carter 1996; Smit 1993; Stakhiv 1993; Watson et al. 1996), in response to the expected or real-time climatic consequences. Such adjustments take place in the social, economic, and ecological spheres (Smit et al. 2000). According to Cannon (2008b), people, when faced with crisis, would behave "culturally" to respond in ways so unique that sometimes they seem to be quite irrational from outside. However, by virtue of the very notion of culture as unique to a system, grassroots responses as processes of cultural adjustments are spontaneous; hence, the grassroots own full autonomy on their actions (Carter et al. 1994). As Smithers and Smit (1997) claim that spontaneous adaptation is the activity of an individual, his decision making of autonomous responses is embedded in social processes that reflect the relationship with other individuals, his networks, capabilities, and social capital where unmanaged natural systems often are hotbed to stimulate them.

The Analytical Framework

To develop the analytical framework of this chapter, vulnerability has been scaled down to baseline vulnerability. Exposure is the key stimulus against which vulnerability can be traced. Scale of analysis is highly important to understand the layers of changes in the vulnerability condition against a given exposure. When exposed to a hazard, individual responds selectively according to the level of basic vulnerability one withstands and sets the priority areas of response. The ability of one to control the parameters that determine vulnerability might be translated into one's capacity to adapt. As for a fisherman, his livelihood depends on the workable condition of a fishing boat. Therefore, during disaster securing the boat is his first priority than saving his own life. It is the spontaneous responses of that particular individual the framework of this present research identifies as "grassroots." In contrast, a poor day laborer who lives in a comparatively unsafe shelter in a risky location and has nothing much to lose materially would migrate to a safer place at the first instance leaving everything behind. Although the fisherman is wealthier than the poor day laborer in terms of their respective asset share, the first one is more vulnerable according to the differences in the priorities. In these sense, the scope of this analytical framework has tended to consider baseline vulnerability of individuals as the most important aspect to examine the effectiveness of grassroots responses.

Figure 1 shows the range of climate variability and on the eve of exposure how sensitivity of the individual is determined based on his access to resources. Priorities of responses are set depending on the baseline vulnerability. The individual then starts to respond in the adaptation process through bringing changes to the physical and nonphysical attributes of vulnerability parameters. This is the boundary of autonomous adaptation as long as there is no external intervention involved (such as planned government intervention). The baseline condition and associated responses together constitute residual impact towards the next layer of vulnerability. This is the point where planned adaptation starts to operate and determines total vulnerability of the system to climate change. It further trickles back and suggests change of state to the sensitivity of individual. Future alteration in planned intervention also takes place based on the changed situation.

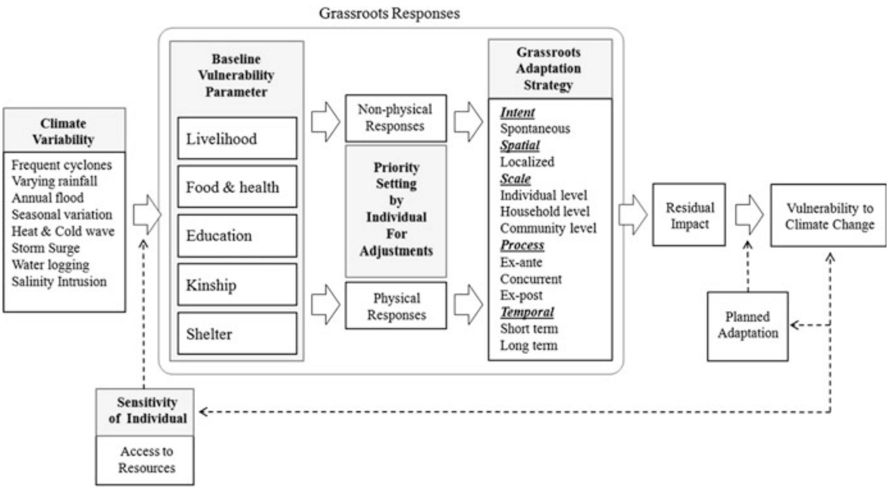

Fig. 1 Analytical framework for vulnerability, adaptation, and grassroots responses

Climate Change Adaptation and Grassroots Responses: The Case of Gabura

Profile of Gabura

Gabura[6] is in the eastern part of Shyamnagar Upazila in Satkhira district of Khulna division in Bangladesh. It is a small island, bounded by Kholpetua and Kopotakhsa rivers, which are subject to year-round strong wind and tidal interactions. It was once part of the Sundarbans.[7] More than a century ago, people cleared this part of the forest for shelter and livelihood opportunities. However, in recent period, excessive reliance on forests is being controlled by restrictions to protect loss of biodiversity.[8] Recently, during the aftermath of extreme disaster, significant portion of inhabitants was forced to retreat from their hereditary occupations of agriculture. At present, 80 % of the economically active population is involved in fishing or activities related to marketing and processing of fish.

[6]Gabura union covers an area of 10,195 acres, with an estimated population of more than 31,115. Most inhabitants (about 96 %) are Muslim. The male–female ratio is 49:51 and literacy rate of this region is 35.9 %. The union consists of 9 wards and 15 villages. 75 % people are involved in fisheries and 20 % rely on crop farming. The rest lives on occupations like industrial labors, rickshaw, and boat puller. The average income is 4000 BDT (BBS 2012).

[7]Sundarbans, the largest mangrove forest in the world, was declared UNESCO World Heritage Site in 1999.

[8]The forest department introduced a “pass” system to restrict the abuse of forest resources.

Most inhabitants, particularly the fishermen, now live along the embankment[9] and on the highlands near the water interface, while farmers live in the middle part.

The way people of Gabura perceive disaster is unique. They are used to typical climate-induced hazards of heat, storm, cyclone, heavy rainfall, and flood. Disaster is part of their daily life as normal as seasonal variation. They are skilled to predict the timing and type of disaster by applying indigenous techniques of observing the weather condition. According to the inhabitants, Gabura is relatively protected, firstly, by the vast natural barrier of the Sundarbans and, secondly, by the embankment. However, "Aila" was the most sudden catastrophe of an unprecedented scale. Within less than an hour, the tidal waves leaped up as high as it could overflow the embankment and rolled into inland washing out every man-made and natural element along its path.[10] Seawater, once entered the inland, could not return to the river and retained for 3 months. The whole island went "green to gray." In addition to physical impacts, vulnerability increased through disrupted livelihoods, long-term displacement of people from their homesteads, and increased health risks due to shortage of drinking water and food supply. Schools remained closed for as long as 2 years. Although the massive momentary shock of Aila had exhausted every possible means to cope with the event at that time, significance of the grassroots responses started to show its upshot at a more profound pace during the 4 years' recovery stage.

Study Approach and Methodology of Field Investigation

An interpretive analysis was done to explain the everyday life in Gabura in relation to climate variability. Qualitative survey was conducted in depth among 20 households to identify their demographic characteristics and perception of hazards, risks, and responses to disaster. Family history of households and their tenure of association with Gabura were critical for selection of interviewees. Afterwards, the unique grassroots responses attributed to their baseline vulnerability were explored through semi-structured interviews. Sample households were selected based on their dwelling location and occupation. Ten households were fishermen with few having business stakes relating to fish marketing and processing, eight were involved in multiple jobs as available and suitable across different season, and

[9]In early 1960 the then East Pakistan Power and Water Development Authority (after independence it is named WAPDA) surrounded the coastal cropland with embankment to protect it from saline water flooding. Apparently, it ensured good cropping in the coastal area, however, from the ecosystem perspective; it has badly altered the natural water–coast interaction, barring the natural siltation process. Consequently the area has gone lower than the sea level and has become subject to water logging and saline water intrusion (Parvin and Johnson 2012).

[10]According to Upazila Nirbahi office, Shyamnagar (local authority) around 41.11 km^2 area of Gabura union was undulated where 4324.97 ha of shrimp land was destroyed, 12,280 households were destroyed, 28 people were dead, 467 people were injured, and more than 30,034 people were affected. More than 3,000 people took shelter in nearby cyclone center and 13,000 people on embankments (Kumar et al. 2010).

the rest two were farmers. Except the fact that the farmers only lived in the middle part of the island, where farmlands got sizeable recovery during last 4 years after Aila, the rest lived in clusters within proximity of the water edge along the peripheral high embankment. Households with firsthand experience in Aila incident were only included in the sample.

In addition, physical features of homesteads including landscape elements, organization, and distribution of homesteads were observed carefully. It helped to understand the spatial manifestation of grassroots responses. Focus group discussion was conducted primarily to unveil the history of community in general and the nature of collective responses. Moreover, cross-checking the authenticity of the household interviews was a secondary concern. Based on the analytical framework, grassroots responses were analyzed in terms of physical and nonphysical key attributes. An effectiveness matrix of grassroots responses was built to understand the level of resilience.

Priority Setting for Grassroots Responses in the Adaptation Process

Neither the buzzword "climate change" nor the issue of "sea level rise" is familiar among the inhabitants of Gabura, except those who received formal education. Nevertheless, they were found highly sensitive to those climate-created stimuli, which would influence to identify their adaptation responses. However, responses vary not only for climatic stimuli but also for the non-climatic conditions (Smit et al. 2000, p. 235). Together they determine the sensitivity of the social system and assist in setting priority towards adjustments. Table 1 depicts a relationship among climate variability, disaster, their impacts, and perception of risk by the grassroots.

Most respondents feel that after the year 2000, nature has been extreme and frequency of disaster intensified. They recognized changes in seasonal variations including increased heat, cold wave in summer nights, untimely rainfall, or no rain however, they impose low to moderate risk on livelihood, food, and health status. There has been increased frequency of cyclones during monsoon, however, they impose low risk on the livelihood and education sectors and cause minor damage to shelter. Typical annual flooding causes short-term displacement and sometimes interruption in education. Increased water logging condition due to heavy rainfall and storm surge including saline retention in the subsoil pose high risk and destabilize most of the baseline vulnerability parameters. These are caused by extreme climatic hazards and eventually they push grassroots responses to the thresholds of limit.

Grassroots Responses Before, During, and After the Disaster

Given the fact that Gabura is incessantly exposed to different degree of climatic hazards, grassroots responses are the inbuilt elements of the daily life of the islanders. It is hard to differentiate from one another as they are overlapping.

Table 1 Perceived climate change impacts by households in Gabura

Climate change stimulus	Climate variability	Disaster impact	Effects	Level of perceived risk
Sea level rise	Untimely rainfall	Disturbed cropping pattern	Loss of livelihood	Medium
	Less rainfall	Disturbed fish farming	Insecurity of food	
	Less seasonal variation	Scarcity of natural fish in rivers and canals		
	Frequent cyclone	Loss of working days	Loss of livelihood	Low
		Temporary interruption of communication	Interrupted education	
		Temporary interruption of schooling		
	Increased heat	Heat stress	Deterioration of health	Low
	Cold wave during summer nights	Chronic fever		
		Pneumonia to children		
	Annual flooding	Short-term displacement	Loss of kinship	Medium
		Medium-term interruption of schooling	Interrupted education	
	Heavy rainfall for short time period	Damage to homestead	Loss of life	High
	Storm surge that crossed over the embankment	Medium- and long-term displacement	Loss of farmland	
	Prolonged water logging	Damage to household assets	Loss of traditional and other livelihood	
		Damage to water supply system		
		Scarcity of food and drinking water	Insecurity of food and water	
		Increased waterborne diseases	Interrupted education	
		Damage to livelihood assets	Loss of kinship	
		Damage to fish ponds	Loss of shelter	
		Long-term interruption of schooling	Deterioration of health	
		Increased salinity of soil and water		
		Scarcity of drinking water		
		Salt in air during summer		

Source: Field Survey, 2013

The interview unveiled the nonphysical and physical grassroots responses before, during, and after disaster that have been categorized in Tables 2 and 3. Aila is the major disaster event in recent years. Therefore, responses after Aila have been considered ex post responses. The key findings are as follows:

Before Disaster

Historically, the geographical setting of Gabura has provided spontaneous choices of cropping, fishing, and other livelihood opportunities. While the fishermen have inherited unique time-bound fishing techniques[11] from the river system of the Sundarbans, farmers held intimate knowledge of soil, water, and seeds that are resistant to flood and saline water. It is the harsh reality that, throughout the year, all have to maintain rationing of drinking water through rainwater harvesting system. The bountiful forest and water system has ensured supply of high-carbohydrate and high-protein daily food.[12] Previous experiences have taught them to store dry food, matchbox, cooker, and cooking fuel (enough for couple of days) on a relatively higher place – a preparedness strategy based on anticipation. They usually maintain extended family networks inside and outside of village through marriage and kinship to secure assistance (usually in monetary form with unconditional loan) during disaster. Timing of schools is scheduled based on the changing time of high tide and low tide. Children take plastic bags to carry books for protection from unwanted rain.

They chose higher land for homesteads along the embankment or internal high-water edges in proximity to their working place. Plantation of mangrove trees[13] along the embankment as well as the periphery of homesteads helps to withstand soil erosion, gusty wind, and wave. Supply of food, fuel, and building materials comes as by-product. Families within blood relation build house around courtyard and share services (e.g., toilet, vegetable gardens, and animal rearing spaces) except cooking. Houses are built on raised earthen plinth.[14] Height of the plinth is determined based on previous mean level of flooding observed. Mud for the plinth is collected through excavating ponds. These ponds are used to retain rainwater[15] for cooking and fish culture. False ceiling with local materials is used to store valuables and insulation from heat. To protect the roof from hauling, they tie bamboo frame or net on the roof and maintain the roof slope less than 40°. Anticipating storm, they tie the roof with nearby trees or ground with strong rope, so that it may not waft away.

[11]They follow a cycle of three "*Gone*"– "*Omabossha*," "*Purnima*," and "*Bosa*" – according to the behavioral pattern of fishes with tidal variation.

[12]The Sundarbans and its streams are source of honey, fruits, edible shoots of trees, fishes, and crabs.

[13]"*Keora*," "*Goran*," "*Golpata*," "*Geoa*," "*Sundari*," Coconut, *Tal*, etc.

[14]Locally called "vita"

[15]Salinity of pond water reduces if the ponds can be retained for at least two seasons, as the salt sediments. The rainwater also helps to reduce the salt content. Water with reduced saline in this way is called "Dudh–Pani" (milk–water).

Table 2 Nonphysical responses of the grassroots in Gabura Island

Attributes of responses	Ex ante (before)	Concurrent (during)	Ex post (after)
Livelihood	Majority involved in crop farming and fishing, few in fish farming	Occupation sectors, i.e., farming, fishing, boat-pulling practices are disrupted	Adoption of alternative sources of income gets priority during recovery stage
	Time-bound fishing strategies[a] based on the lunar calendar		Fishing from the river becomes predominant occupation
	Cropping pattern based on the quality and classification of soil		Male members from poorest families travel to nearby towns for jobs
			Forced to enter into the Sundarbans and narrow canals for collection of honey, wood, and fishes
Food and Health	Sufficient consumption of locally available foods with high carbohydrate and protein on daily basis across all classes	Less consumption as norms impeded by food shortage	Less consumption as norms impeded by food shortage during recovery stage
		Consumption of wild fruits (i.e., Keora) and seeds from the Sundarbans during extreme events	
Education	Setting up school hours according to the timing of high tide and low tide	Receipt of education disrupted	An increased number of children receive education with the belief that they may change family hardship in the future through jobs in government sector
Kinship	Extended family structure for shared assistance	Immediate assistance comes from family members and neighbors within village level during disaster	Financial assistance from relatives living in town in the reconstruction phase
	Safeguarding strong kinship networks within the same community		
	Female children of the family receive early marriage and usually sent out of the island as long-term strategy of extending kinship beyond Gabura		
Shelter	Few literate people save money for shelter	Immediate response during extreme condition includes securing educational certificates, legal documents of land ownership than the physical shelter itself	Increased interest in saving money for shelter repairing and construction

Source: Field Survey, 2013

[a]Locally called “*Gone*”

Table 3 Physical responses of the grassroots in Gabura Island

Attributes of responses	Ex ante (before)	Concurrent (during)	Ex post (after)
Livelihood	Selection of agricultural land in relatively higher part of island	Relocating livelihood assets (i.e., poultry, livestock, fish net, boat) in higher place near roadside/embankment or temporary elevated structure or even on the rooftop	Increased engagement in shrimp farming due to salinity intrusion during Aila
	Shrimp farming in the lower part		
	Narrow canals to control saline water for fish farming		
Food and Health	Storage of dry food, matchbox, cooker, cooking fuel in relatively higher place	Clay pots sealed to secure drinking water during storm surge	Underground storage of foods, matchbox, cooker, cooking fuel after experience from Aila
	Rainwater harvesting through use of plastic sheet on roof surface to collect water and preservation in clay pots	Temporary latrine on stilt above water closed to embankment	Increased protection measures for homestead ponds
	Homestead ponds for sweet water fish culture and water with reduced saline content[a] for cooking	Temporary cooking facilities on top of bed or any higher place available	Homestead/kitchen garden as source of vegetable for daily consumption
Education	Use of plastic shopping bag to protect dry clothes and books during extreme weather	Primary schools and mosques used for cyclone shelters during disaster	
Kinship		Use of temporary boats either made of banana tree or large cooking pots to maintain connection with relatives and rescue effort	
Shelter	Appropriate mix of mangrove plants to withstand soil erosion in river banks	Children moved to elevated structure or even on the rooftop	Compact and organic distribution of homesteads during the four years' recovery phase after Aila
	Raised earthen mound for plinth of house or use of stilt	Construction of makeshift shelter along the roadside and embankment	Selection of high land to build shelter along both sides of the embankment

(*continued*)

Table 3 (continued)

Attributes of responses	Ex ante (before)	Concurrent (during)	Ex post (after)
	Use of locally available materials for construction of shelter	Bracings made with chords and bamboo to avoid upward hauling of the roof during cyclone	Homestead forest in the periphery to protect from gusty wind and source of wood for shelter repair/ construction
	Construction of smaller false ceiling for storage and shelter		Increased height of the plinth based on the flooding experience in Aila
	Roof slope less than 40°, use of bamboo frame bracing and fishing net on roof surface to protect from gusty wind		Roofing material changed from thatched roof to CI sheet and preferably asbestos
	Annual maintenance of weaker parts of built structure		

Source: Field Survey, 2013
[a]Water with reduced saline content is locally called "Dudh-Pani." The literal translation in English should be "milk–water"

During Disaster

During disaster, the most preferable option is to stay at homestead as long as possible. During regular flooding and storm surge, people keep on waiting in the house observing how high the water gets in and build elevated structures[16] for storing foods, valuables, and livestock. The flood hinders livelihood activity and they pass lazy time on furniture above flood level, and use moveable cooker for food preparation. Children move to a higher place, such as on false ceiling and sometimes even on rooftop. During long-standing inundation, people move to makeshift shelters on embankments or nearby cyclone shelter, usually schools. However, such makeshift shelters are inadequate in numbers. Temporary shelter consists of one single room to accommodate the whole family. Shortage of food supply leads to consumption of wild fruits and seeds. Immediate assistance comes from family members and neighbors within village level during disaster. Handmade boats[17] or large water pots as substitute of boats are used for communication. Interestingly, both the higher- and lower-income population travel to nearby city centers for social safety by choice and livelihood by need, respectively. It is hard for

[16]Locally termed "Matcha"

[17]Locally called "Vela," made of bamboo or banana trunk

the middle class to opt for migration. Neither the job opportunity in cities suits their class, nor can they risk on their last piece of land to be illegally grabbed.

After "Aila"

By nature, the people of Gabura did not learn to save money for the future; rather, they followed a day-to-day livelihood path. Therefore, during recovery stage after a major disaster like Aila, search for alternative sources of income gets priority as the regular job options are disturbed. As farmland goes under long-term inundation, fishing from rivers becomes a predominant response. Shift to large-scale shrimp farming was limited to powerful elites as it was never a labor-intensive sector. Consequently, some male members from poorer families migrated to town centers for jobs. Many (including females) were forced to enter into the Sundarbans to collect honey, wood, and fishes. Less consumption was established as norms impeded by food shortage after Aila.

Nevertheless, during the 4 years' recovery period after Aila, the grayed landscape is showing signs to get greener. Homestead level ponds, vegetable gardens, and forests are being reinstated with cautions (increased plinth level, high trees in the windward direction of homestead, raised embankment for the pond to withstand flood, roofing materials changed from CI sheet to asbestos, etc.) that are learned from Aila experience. The number of children receiving education has increased with the belief that they may change family hardship in the future through better jobs. Financial assistance in the form of unconditional loan from relatives living in town has contributed immensely in the reconstruction phase. However, it is limited to the well-off families only. Increasing awareness to save money for future survival responses is evident. More dense and organic distribution of homesteads is taking place along the embankment. Briefly, with many creative interventions, grassroots responses are being evident as ex post measures after Aila. However, confusion remains among them, whether these adaptations, although improved from the past, would withstand a next disaster as extreme as Aila.

Effectiveness of Grassroots Responses

Analysis of grassroots responses in relation to the effects of disaster reveals their effectiveness, which has been presented in Table 4. The evaluation in terms of strengths and weaknesses suggests that most responses are quite effective in relation to the typical hazard condition including minor weaknesses. However, the analysis also reveals that some of the grassroots responses did not succeed during extreme event of Aila, which was too unpredictable in nature. During typical hazards, the indigenous knowledge base helps better adaptation through decisions to change cropping and fishing pattern and optimum utilization of time in different livelihood sectors. Usually, the natural weather indicators help better preparedness on the eve of any exposure. Yet during extreme event, it failed to anticipate the severity and timing of hazard. Field survey revealed that most interviewees could hardly perceive the extremity of "Aila." Although the resourceful natural system

Table 4 Effectiveness of grassroots responses

Grassroots responses	Typical hazard		Extreme event
	Strength	Weakness	
Nonphysical responses			
Adoption of new livelihood strategies	Multiple livelihood options and income opportunities	Loss of traditional occupation	×
	Adaptation to changed environment	New land use distribution detrimental to ecology	
	Male–female equal participation		
Increased interest in receiving education	New job opportunity	Loss of labor force in traditional occupations	×
	Increased self-dependency and awareness	Displacement	
	Increased tendency of savings		
Indigenous knowledge-based weather forecasting	Better adaptation with mother nature		×
	Productive cropping and fishing pattern		
	Optimum utilization of time		
	Better preparedness to fight with disaster		
Short-, medium-, and long-term displacement	Alternative skill for livelihood	Displaced from the hereditary land	√
	New networks	Declination of community bondage	
		Destruction of traditional lifestyle and settlement	
High level of kinship and social capital	Strong social ties irrespective of occupation, religion, ethnicity, or economic status	Increased social liabilities	√
	Mutual trust		
	Cooperating attitude		
	High human value		
Physical response			
Life safety measures and protection of livelihood asset	Initial preparedness for the recovery stage		×
Increased dependency on natural resources from surroundings and the Sundarbans	Alternative source of income	Detrimental to natural biodiversity	○
	Source of local and organic construction material		
	Source of high-nutrient food supply		
	Protection from cyclone and storm surge		

(*continued*)

Table 4 (continued)

Grassroots responses	Typical hazard: Strength	Typical hazard: Weakness	Extreme event
Rainwater harvesting in homestead	Source of potable water	Probability of waterborne health hazard	○
	Source of basic nutrient from sweet water fishes		
	Reduced salinity		
	Contribution to the homestead morphology		
Plantation in homesteads	Reduced heat	Damage to shelter due to fallen big branches of trees during storms	×
	Source of food and fuel		
	Source of building construction material		
	Protection from gusty wind and storm surge and soil erosion		
	Contribution to the homestead morphology		
	Optimum use of homestead leftover space		
Use of community infrastructure	Adaptive reuse of embankment	Deterioration in longevity of infrastructure	√
	Safe shelter during disaster	Unhygienic physical environment due to adaptive reuse	
Recycling and reuse of natural and man-made resources	Efficient use of resources	Depletion of resource due to repeated use	√
	Sustainable use of resource		
	Cost efficiency in shelter reconstruction		
Protection of shelter based on indigenous knowledge	Preservation of traditional homestead and settlement morphology		×

Source: Field Survey, 2013
√ effective, ○ effective with limitations, × failed with limited effectiveness

has offered an array of livelihood opportunities, traditional occupations could not sustain the aftermath of the extreme event. The settlement has undergone a slow process of deterioration in ecology. Growing literacy among the inhabitants has been opening new avenues for livelihood and enhanced preparedness. In contrast, the traditional skills are diminishing and stimulating displacement to make way for the formal scientific knowledge. However, after extreme event like Aila, education system terminated as long as 2 years. Most interestingly, the nonphysical responses of migration and safeguarding kinship were powerful coping strategies during extremes.

Among the physical responses, the typical life safety measures have been proven useful during both the normal and extreme hazard conditions. However, they lost their usefulness as the impact of “Aila” had lasted for a longer period. Even after extreme events, the natural system of the Sundarbans requires time to get back to its earlier state. Yet excessive dependency on the Sundarbans for livelihood and food supply is exhausting the natural setting. Cyclone shelters and schools, although very limited in number, play positive role through providing alternative shelter during all events including extremes. Physical responses like rainwater harvesting and homestead vegetable gardens are critical to meet requirement of safe drinking water, supply of nutrition, and other cost-saving household income during and after disaster. They are highly vulnerable during extreme events as whichever falls in the direction of storm surge gets wiped out.

Terminologies such as "community-based adaptation," "participatory adaptation," "climate change adaptation from below," and even "grassroots responses" bear romanticism within them because of their inherent "people-centered" notion. There is a wider belief in theory and practice that grassroots can solve everything. However, in reality, during disasters in coastal settlements, grassroots remain handicapped due to limitation of adequate resources and institutional support. In extreme event, livelihood options and education system are severely disrupted. As it is an independent parameter of baseline vulnerability, the command on other dependent parameters like food, health, and shelter naturally are invalidated. During the aftershock of extreme events, even the bountiful resource base of the Sundarbans enters into a crisis state and fails to meet the demand side with its disrupted supply side for a while. Recalling from the history, people know that there has been an extreme event in every 5–10 years or so. The gap between extreme events has been decreasing over last two decades. Nevertheless, successive improvements in grassroots responses are pushed to the "critical thresholds" (Adger et al. 2003) as every time new hazards hit with higher extremities.

Climate Change Adaptation Through Grassroots Responses: Future Direction

It is somewhat unanticipated that people often become vulnerable because they are excluded from safer places due to their structural inequality and forced to choose locations that are exposed to extreme events; at the same time, the vulnerable locations have provided them with livelihood options (Kelman and Mather 2008; Lewis and Kelman 2010). In this sense, the natural system of the coastal settlements is not to be blamed but the governance system that has set up unequal access to resources resulting into deprivation. Cannon (2008b) argued that culture plays a powerful role for people willing to live in peril where livelihood is able to connect to well-being. Hence, willingness for self-protection comes naturally with livelihood and well-being. This is the limit of an individual's response without any external intervention (Cannon 2008a). Beyond this point, external incentives should be required either in the form of societal protection or through a favorable government that would facilitate grassroots responses more effectively through optimum allocation of resources. The empirical findings of this chapter have an important implication suggesting insights to facilitate grassroots responses in the process of climate change adaptation.

Evidence from this study suggests that the first step to reduce the baseline vulnerability is to facilitate livelihood options and ensure their long-term sustenance. The study undoubtedly revealed storm surges that overflowed the embankment causing long-term inundation of inland pose highest level of risk through disrupting livelihood and other parameters of baseline vulnerability. It is of extreme necessity to scrutinize the existing settlement morphology and identify what is problematic towards long-term inundation. Therefore, more sustainable settlement-planning strategies have to be formulated which would not only reduce the risk but also offer scope to nurture traditional livelihood practices. One of the major challenges should be to upkeep the delivery of education, which can be an escape route for many in the future through better livelihood opportunity and scientific knowledge base. Therefore, disaster adaptive schooling system (physical design or policy support) has to be ensured, so that delivery of education may not be stopped under any circumstances. The number of schools has to be increased in strategic locations, so that they may cater adaptive utilization during disasters and overcome the present supply shortage of cyclone shelters.

Contrary to the expectations, as the indigenous way of anticipating weather events fails to predict extreme event, awareness should be created among the grassroots, which would result in increased reliance on scientific warning systems. Individual’s life safety measures are not that useful in the end until one’s livelihood assets are secured during disaster. New policy and planning responses are needed towards a comprehensive safety net. Biodiversity of the Sundarbans should be protected at any cost. However, an equitable policy support is necessary to establish a sustainable baseline supply chain of food and fuel for the indigenous people. Strong social ties of mutual trust and kinship have to be properly utilized for both individual and collective disaster responses. In this regard, some of the individual level responses (i.e., rainwater harvesting and gardening in homesteads) can be scaled up to community-level practice to build on collective resilience. Responses to the improvement of shelter are piecemeal. Research-led design interventions are needed to combine traditional building technologies and science of building to cater resilience and shelter’s sustainability.

Nevertheless, strength–weakness matrix of grassroots responses demonstrated that “displacement” either temporary or permanent has been a common phenomenon during all disasters. Gabura is a disaster-prone island and disaster extremities will increase year on year due to unavoidable consequences of sea level rise. Long-term strategies may be adopted through creating diversified job opportunities in nearby safer locations, so that people may respond through trading off their risky living place with better livelihood options. The process of planned gradual relocation over a decade or so would eventually leave less people exposed to future extremes in places like Gabura. The resulting settlement initiative would provide reasonable setback for both the Sundarbans and Gabura Island to recover back to their earlier state of resourcefulness. This strategic intervention should be integrated into the regional planning strategy for the central government to redistribute and decentralize resource base. As a result, it would ensure equitable scope of resource share for the vulnerable communities of the coastal settlements to build up nationwide resilience.

Conclusion

Climate change is a reality and cannot be denied. Living with disaster is part of everyday life for millions of people dwelling in the disaster-prone areas of Bangladesh and in other places of the world. However, the baseline vulnerability arisen from the root causes of this large population's socioeconomic strata is yet intimately embedded in the mainstream understanding of disaster preparedness through either risk reduction or adaptation. This is probably because preparedness has been still enclosed around the dimensions of broader hazard-centric paradigm than considering as an active socioeconomic development process (Gaillard 2010; Kelman and Gaillard 2008). Neither has been many attempts visible to place adaptation scholarship within the paradigm of disaster risk reduction (Kelman and Gaillard 2010).

The present study confirms that adaptation starts at local level as part of the individual's fundamental urge for survival. Grassroots responses are spontaneous and they facilitate community to adapt to climate variability respective of their socioeconomic status. Yet the responses are inadequate during extreme event. Mismatch is evident among the increasing level of extremities in disasters from climatic hazards and the improvement of grassroots responses over time. Integration of grassroots response with relevant policies and development mechanisms of the existing developmental programs to cater the needs of climate variability can be a first step. Integrated policy to address the baseline vulnerability of the community is important. Interventions compatible to the coastal settlements system itself may significantly reduce its vulnerabilities and create opportunities for the country's large coastal population. Experiences from the category one cyclone "Aila" revealed weakness of existing grassroots responses. However, the importance of community-led adaptation can never be ignored. Rather, they need to be adequately equipped with reasonable climate change adaptation planning and policy responses. Failure in doing so may pose a threat to extinction of indigenous knowledge base climate change responses and lead the large coastal population to an uncertain future.

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Climate Change Aspects of International Knowledge Exchange About Water: Experiences from Mozambique and Ecuador

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Abstract

By outlining the central role of water in the global warming process, the necessity of international collaboration in terms of tertiary education in hydraulics and hydrology is being derived. In this chapter an integrated approach of knowledge exchange in the framework of a descriptive education concept and applied university research projects is being elaborated. The focus is placed on descriptive teaching of fundamental flow physics, the application of a sophisticated but open-source software tool for the prediction of flood areas, and a small hydropower project plant which was designed to enhance the living quality of indigenous people in the middle of Ecuador's rainforest. These projects were mutually realized with committed and open-minded local partners.

Keywords

Water • International knowledge exchange • Descriptive education concept • Hands-on projects • Flood prediction • Small-scale decentralized renewable energy systems

Introduction

Over the past and the current century, the so-called developed part of the world has almost entirely exploited the Earth's resources which have been built up over billions of years. And it was only in 1972 when the so-called civilized part of the world realized "the limits to growth" which were formulated by the Club of Rome. The irreversible consumption of fossil fuels satisfies the quenchless hunger of an exponentially increasing living standard. This process goes in line with (a) a rapidly growing world population and (b) a continuously growing percentage of people benefitting from technical progress. The latter fact is truly a great achievement but nevertheless still a few percent of the people live on the cost of the majority.

With the UN millennium goals (United Nations 2013), the gap between the rich and the poor should be reduced which means to significantly enhance the living quality in developing and emerging countries. However, one has to learn from the mistakes mankind has made and support the erection of a sustainable infrastructure in such regions. Therefore, one does not only have to set an example but also to put effort in developing smart and peripheral renewable energy supply units and to implement them in collaboration with the local people. It is needless to mention the imperative of curtailing the impact of global warming on the Earth's ecosystems.

Climate Change: Greenhouse Effect

Global warming is a highly complex physical phenomenon; it is a consequence of solar energy entering the Earth's atmosphere as shortwave radiation, whereas its longwave reflection is captured to a certain percentage by the so-called greenhouse gases. Without the natural greenhouse effect, the world would look differently – and a lot (32 °C) colder (Roedel 2000). However, there is a quite instable equilibrium between the planet's temperature and the greenhouse gas content of the atmosphere.

When the shortwave radiation from the sun enters the atmosphere, only a negligible fraction is being reflected at the outer atmosphere and the rest reaches to the ground. There, dependent on the material, parts of the rays are directly (same wavelength) reflected. This process is called albedo effect; glaciers, e.g., directly reflect 30–75 % of the sun's radiation, whereas liquid water only mirrors 5–22 % and clouds 60–90 %. The rest of the energy is absorbed by the Earth's surface which radiates heat waves back to the atmosphere. So-called greenhouse gases act membrane-like and reflect these longwaves back to the Earth whereupon a gradual temperature rise ensues. Greenhouse gases are mainly water vapor (H_2O, CO_2 equivalent due to strong temperature dependency not allocated), carbon dioxide (CO_2), methane (CH_4, 25 times CO_2 equivalent), and nitrous oxide (N_2O, 298 times CO_2 equivalent), which is produced by nitrification and denitrification (Sloss 1992). Water vapor in the atmosphere contributes, for instance, 36–66 % to the natural greenhouse effect; carbon dioxide and methane come up to 9–26 % and 4–9 %, respectively. While the CO_2 content increased from the preindustrial era from 280 ppm to 390 ppm in 2011, it is responsible for 60 % of the anthropogenic greenhouse effect. Methane increased from 730 ppbV in 1750 to 1,741 ppbV in 1998. Nitrous oxide (N_2O) emissions arise mainly from cropland (69 %) and grew from about 270 to 323 ppbV and account for 6 % of anthropogenic global warming (Blasing 2013).

It can be concluded that 50 % of the anthropogenic impact on climate change can be traced back to the energy sector where mainly CO_2 is being emitted (Schabbach and Wesselak 2012). The cement industry, deforestation, and mainly agriculture, particularly livestock farming and rice cultivation, add up to the other half (IPCC 2007).

According to the Intergovernmental Panel on Climate Change (IPCC), the anthropogenic impact on global warming is in all probability. Between 1906 and 2006, the spatial average close-to-ground air temperature has risen globally for about 0.74 K $\pm$ 0.18 K (IPCC 2007). The oceans, with a much greater specific heat capacity, heated up by 0.037 K from 1955 (surface temperatures increased by 0.6 K) which corresponds to an atmospheric temperature rise of 11 °C (NOAA 2007). The risky issue is that ocean streams are density driven so that they react very sensitively on changes in temperature or salt contents. The Gulf Stream, e.g., carries northwards twice the heat every day that is produced annually by all the thermal power plants worldwide at a velocity of 1.8 m/s at Florida's coast (Ball 2001). However, according to the IPCC (2007), there is a probability smaller than 10 % that a transition of the streams takes place before 2100.

Depending on the future emissions, the IPCC predicts an atmospheric temperature rise with respect to the preindustrial era (1750 CE) of 1.1–6.4 K in 2100 (IPCC 2007). For comparison, the greatest warming after the last ice age was 1 °C within a millennium (Leggett 2005). It is important to mention that local impacts show greater amplitudes than global mean values do. A global 4° warming means, for instance, a temperature rise of 8 °C in the Mediterranean (Wicke 2013).

Water: Global Warming's Central Element

Water as life's central element plays an important role in the global warming context. Water in its three phases – gaseous (0.001 % water vapor), liquid (97 % saltwater and 0.7 % freshwater), and solid (2.3 % ice) – has got a significant impact on the Earth's climate. The oceans absorb CO_2, water vapor is the number one greenhouse gas, and the ice-albedo is the most substantial rebound effect (see below). Even more important rising temperatures affect the hydrologic circle immensely. On the one hand, greater water vapor contents will lead to a greater probability and more severe thunderstorms with subsequently following flood events, and on the other hand, water shortage will increase dramatically. According to Hare, a temperature rise of 1 °C with respect to the preindustrial era will imply 400–800 million people living in water-shortage areas by the 2020s; at 1–2 °C rise, a peak risk of 1.5 billion by the 2050s follows and a rise of 2.5 °C makes 2.4–3.5 billion people suffer from water shortage (Hare 2005).

Katrina 2005, Rita 2005, Ike 2008, 243 hurricanes only in April 2011 in the USA, Irene 2011, Sandy 2012, and the latest striking storm in Oklahoma in 2013 underline that the recurrence interval of such events becomes shorter and shorter. In Germany, for instance, historical floods were recorded in the years 1342, 1501, 1787, 1899, and 1954. Devastating floods then occurred in 1991, 1999, 2002, 2005, and 2013 which makes global warming effects obvious, while there are regions on Earth much more prone to flood fortification.

Hydrology and hydraulics are therefore the basis of climate change adaptation.

Attenuating and Cumulative Effects on Global Warming

Aerosols in higher layers, e.g., reduce the planet's temperature; in lower layers or even on snow or ice, they increase global warming immensely. Particles in the atmosphere reflect the incident sunlight back to outer space, whereas on snow, for instance, they absorb the energy and warm the planet's surface. Especially sulfate aerosols are said to have a cooling effect as the particles in the atmosphere shield the sun's radiation. It seems bizarre that sulfate filters of coal-fired power plants have a negative effect on the climate. The reduction of the ozone layer actually cools the planet, too. The radiation is not absorbed by the ozone in the stratosphere anymore yet in the troposphere as it reaches there more likely (-0.15 ± 0.10 W/m^2). However, the outer layer, the stratosphere, is cooler and therefore cools the troposphere more pronounced than the absorption takes place.

The so-called ice-albedo rebound effect, in contrary, enhances warming. While glaciers melt their surfaces shrink which leads to less reflection and therefore more absorption of sun radiation. The hydrogen-vapor feedback is yet another self-reinforcing factor which, however, cannot be traced back to industrialization. At greater temperatures air can hold more hydrogen vapor, which is yet another greenhouse gas that boosts global warming (Rahmstorf and Schellnhuber 2007). Taking the impact of water vapor on the natural greenhouse effect into account a not negligible fraction of global warming will result from its rebound effect.

Greenhouse gas molecules do have different life spans. In average CO_2 is being dissolved in the oceans after 5 years, although it is released again so that 30 % of the anthropogenic CO_2 will stay in the atmosphere for a couple of centuries and 20 % for a couple of millennia. Methane has a life span of 12 years (IPCC 2007) and nitrous oxide even 114 years.

Consequences of Global Warming

The consequences of global warming are versatile. Melting glaciers lead to a greater sea level (0.19–0.58 m (IPCC 2007)); the vegetation will change; deserts will grow. These issues will have a direct impact on habitats of flora and fauna. Regionally, an increase of 1–2 °C carries substantial, above 2 °C serious dangers (Hare 2005), whereas the total collapse of ecosystems is feared at 3 °C ascent. But it has also got a crucial impact on mankind, mainly through food production (although plant growth increased by 6 % between 1982 and 1999 due to a greater CO_2 content (Nemani et al. 2003), the agricultural production will develop locally different; however, a global reduction of 3–16 % is assumed by the World Health Organization). Higher temperatures lead to greater evaporation which enhances the probability of hurricanes or massive floods threatening animals and people, destroying the harvest. Geopolitical problems, e.g., due to lack of water or food impend and lead to more environmental migration. The financial damage of global warming was assessed by the German Institute for Economic Research to sum up to US$200 billion; the Stern review emanates from 5 % to 20 % loss of the global economic performance. Every region of the world will be affected by global warming, but the poorest that are not able to protect themselves against extreme conditions will be hit hardest (PICIRCA 2012). According to Hare “Africa seems to be consistently amongst the regions with high to very high projected damages” (Hare 2005). Global warming is the first man-made global threat; however, the ones suffering most from it are not its major contributors.

Adaptation to Global Warming

People had to adapt to their environment ever since. All over the place, they suffered from thunderstorms and the subsequently following flood events. Our ancestors had to learn how to cope with extreme climate or weather conditions and drought periods. The major step of mankind to civilization was the control of natural runoff that in some areas even made settlements possible. Freshwater needed to be held back in times of over capacities and released when the crops required it. That process marked the end of the Neolithic Age which took place in the so-called Fertile Crescent (Pleticha 1995). Although a bit later, one of the most impressive monuments that document the effort that has been made to protect people from floods has been erected in Egypt during the Cheops dynasty (approx. 2620–2580 BCE, when hydrologists were worshipped as high priests):

Sadd-El-Kafara, a 10 m high, 45–82 m wide and 61–112 m long dam. There are numerous examples for adaptation technologies in terms of protection from natural hazards worldwide.

Flood control became even more important during the industrial revolution when the risk potential grew enormously as almost all crafts needed water and settled close to rivers. And nowadays, imagine the economic threat of a flooded subway network. As elaborated above, the risk of such hazardous floods increases dramatically due to global warming. Even in Central Europe which is a region not prone to an enhanced thunderstorm probability, extreme flood events occurred more often in recent times. To cope with the challenge, Bavaria's (Germany) adaptation method is a 15 % supplement on the previous design discharge which induces an extensive enlargement of retention potential and embankment strengthening (KLIWA 2012).

International Knowledge Exchange About Water

Academic Education

In this heavily interconnected world knowledge can be exchanged easily (e.g., through wikipedia.org). And it is evident that knowledge exchange has always been the base of development. The permanent gains of cognition and perception, however, convey complexity which requires specialists to handle certain responsible duties. The word exchange means mutual give and take. Thus, international and intercultural knowledge exchange is essential for the solving of regional and global current and future troubles. Primary education, which is aimed to be made accessible to every child (United Nations 2013), is the first step only. Fundamental tertiary education for an appropriate fraction of people (for the smartest not for the richest) is essential for the sustainment and development of good living conditions. The universities and academies have to make sure that knowledge which is accessible at all hours all over the world is being prepared, shared, explained, and set into the right context. Enthusiastic knowledge imparting which is important for the learning success can be handled by passionate pedagogues only. At Technische Universität München (TUM), a concept for fundamental hydraulic education has been developed and conducted over several years. It is based on the train of thought that education has to follow the same path research does (Rapp 2012):

Observe → comprehend → deduce → challenge → apply

This descriptive method has been quite successfully implemented in conjunction with the von Humboldt principle (bond between research and education) and hands-on projects. To share the knowledge and the lecturing experiences internationally, the "Association for International Knowledge Exchange" (German: Verein zur Förderung des internationalen Wissensaustauschs e.V.) has been founded in Munich. In the following some of the experiences gathered in Mozambique are being described. A hands-on project where students from Ecuador and Germany applied their knowledge will be described in the section "Renewable Energies in Developing and Emerging Countries".

Experiences from Mozambique: Flood Protection

Collaboration TUM-UEM

In developing and emerging countries, the protection standard is still very poor. Ever since, Mozambicans, e.g., have suffered from disastrous floods. A tragic example is the year 2000 Limpopo flood which caused some hundred deaths and hundreds of thousands who have lost their homes (650,000 according to GIZ). Only 1 year later, a flood devastated the Zambezi banks. The reasons are on the one hand geographical and topographical and on the other political and socioeconomic. The great African streams Zambezi and Limpopo flow through Mozambique before they discharge into the Indian Ocean at Africa's east coast. After centuries of colonial suppression, Mozambique gained independence only in the mid-1970s. A bloody civil war followed which was aggravated by the Cold War claiming approx. 5 % of the population dead and countless injured. Africa typical threats, e.g., poor educational standard or diseases like malaria or AIDS, contribute to prevent Mozambique from developing. Since the end of the militant actions in the mid-1990s, a gradual improvement, especially in the education sector, can be noticed. Academic structures are being established in the framework of ambitious policies, although the country depends on massive support from international institutions.

To enhance the education of Mozambican engineers, collaboration has been established between Universidade Eduardo Mondlane (UEM) in Maputo and TUM, Germany, and is based on a Memorandum of Understanding between the two federal states. Several courses have been given so far by German lecturers and the hydraulic laboratory of UEM has been assessed and improved through provision of measuring techniques as well as training of the staff (see Fig. 1). Special software has been developed to evaluate these experiments but also to predict, e.g., transient flow phenomena such as water hammer in penstocks. The codes have been written in Octave – a MatLAB substitution which is free to use and to modify (www.octave.org).

Hydrodynamical Approach of Flood Area Prediction

Fluid flows are generally three dimensional and time dependent what makes the partial differential equations that were derived independently by Claude Navier and Gabriel Stokes almost 200 years ago solvable for a handful laminar problems only (e.g., very low velocities like in veins or groundwater flow). The default flow condition, however, is turbulent where a chaotic behavior can be noticed. To predict such flows, the so-called Navier–Stokes Equations have to be solved at discrete points in space and at certain time steps. The more turbulent a flow is, the finer the computational grid has to be and the time step shorter which makes the solution of a relevant industrial or environmental problem computationally unaffordable or even physically impossible. Therefore, different strategies have been developed to cope with this challenge.

Fig. 1 Practical courses and digital transient pressure measurements in the Laboratório Hydraulico of Universidade Eduardo Mondlane, Maputo, Mozambique

For the prediction of flood areas, the state-of-the-art method is to solve the 2D shallow water equations numerically. Deriving the shallow water equations from the three-dimensional Navier–Stokes Equations, the vertical momentum is being neglected and the velocity in the horizontal direction is depth-averaged (Beffa 1994). The momentum balance in the z direction becomes the description of hydrostatic pressure distribution. Integration of mass conservation over the flow depth leads to a transport equation of the flow depth.

For these reasons, the Navier–Stokes Equations can be simplified in such way that they can be applied to solve even great domains, though the preconditions, hydrostatic pressure distribution, and a comparatively small vertical velocity component have to be met. These assumptions generally hold very nicely in natural waters where exact specifications of the bounding geometry are lacking so that the simulation strategy provides significant information.

At TUM's Chair for Hydromechanics, a shallow water equation solver based on the open-source software package OpenFOAM (www.openfoam.org) has been developed to approach such problems efficiently. The solver called shallowFoam and the underlying software package OpenFOAM have been developed under the GNU license agreement so that it is free to use and to customize for any purpose. For the post-processing step, the freely available software ParaView is applied.

Especially in developing countries, this approach has got manifold advantages. Firstly, open-source code licenses are free of charge and the code can be adapted to whichever problem. Secondly, there is comprehensive support available on the Internet because of countless OpenFOAM users worldwide. Thirdly, this software package belongs to the most powerful tools for the solving of partial differential equations like the shallow water equations. Fourthly, the program is massively parallelized and with the solver shallowFoam flood scenarios of even great computational domains can be simulated on servers all over the world in an acceptable timespan. Finally, a link has been programmed to convert GIS data to be OpenFOAM standard (e.g., Jud et al. 2011).

A crucial drawback of the method is that – except for ParaView – graphical user interfaces (GUIs) are lacking which makes the application not easy to handle or even inconvenient for beginners. However, additional university courses on numerical river hydraulics form the integrated approach that the Association for International Knowledge Exchange follows.

Flood Area Prediction

Simulation of flood events requires input data such as the topography (underlying the computational grid, roughness, and discharge). Worldwide topographical data can be downloaded for free – at least at a resolution of 25 m × 25 m – from http://eoweb.dlr.de:8080. Depending on the assignment, finer resolutions are available at different websites. Roughness of the ground depends mainly on the land use and can be gained from aerial photos (e.g., Google Earth).

As profound hydrologic data are mostly not available in developing or emerging countries, extreme flood event discharges can be reconstructed by so-called inverse simulations (Motzet 2003) or they can be reconstructed from the Global Runoff Data Centre (German Federal Institute of Hydrology 2013). By modifying the inflow into and rainfall onto the surveyed region, the different simulation results are being compared with observed data. At the best match, the required parameters can be identified. The procedure has to be done for different events which will help to derive flood probabilities. Future events with certain occurrence probabilities can be subsequently investigated. Safety margins to account for increasing precipitation intensities due to global warming can be considered in the computations (KLIWA 2012). Figure 2 exemplarily depicts a flood risk plan gathered through shallowFoam simulations and illustrated in ParaView (blue = low risk, red = high risk).

The consideration of global warming effects, thus increasing peak discharges, in these numerical simulations leads to appropriate flood risk plans which are the basis for adaptation means.

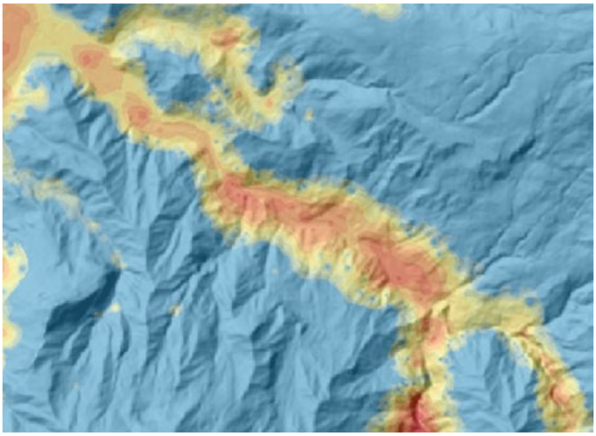

Fig. 2 Risk potential: example for a design flood in an arbitrary domain (From Schäffler et al. 2011)

Remarks on the Academic Concept

This integrated approach – fundamental and depictive hydraulic education, provision of free-to-use software, computer training, and enabling of discrete modification and application – helps to cope with the water-based challenges arising from climate change. The fundamentals in hydraulics are needed for the planning of drinking water supply, wastewater discharge, flood protection, irrigation, and many more.

In the example in the section "Flood Area Prediction," a certain approach to identify areas prone to damage and to ascertain the protection of the people has been elaborated.

Renewable Energies in Developing and Emerging Countries

Energy has become an essential livelihood. What energy means to people can best be assessed where it is not accessible to everyone. William Kamkwamba, an uneducated engineer from Malawi, is a renowned genius. He has built a wind turbine from scrap supplying his family shack with electric light and even being able to charge other people's mobile phones (Kamkwamba and Mealer 2009). Access to power changes life completely and makes development possible.

However, providing the global population with Western European standard will soon lead to a total environmental collapse which thwarts Millennium Goal 7 (ensure environmental sustainability). Despite the additional warming effects and general availability of resources (even for uranium which is by far no alternative), their accessibility is limited (Schabbach and Wesselak 2012). The so-called energy turnaround implies renunciation from a centralized and grand-scale electricity generation to communal renewable energy plants with high harvesting factors (energy gain over energy need for erection and operation).

Conventional plants receive the fuel from remote point sources mainly in Asia, America, Australia, or Africa. The plants are not where the sources are. The combustion of fuels in grand plants and the ensuing delivery to the end user are physically and economically more efficient rather than the resource distribution to the end user with local generation. Renewable energy sources are being used where they appear. For example, it is hardly imaginable that wind is taken from all over the world to a central spot where one huge turbine generates power for a whole city. Hence, where development takes place, the focus has to be placed on small-scale decentralized renewable energy systems.

Hands-on projects based on these principles collaboratively realized with the local population create acceptance enable them to understand the technique and maintain the facilities on their own while rural areas are ecologically friendly empowered (Rapp et al. 2012). And a not negligible side effect is that the added value stays local. One project that has been realized in a smaller scale only is being presented in the following.

Overview of the Project

In 2010 a group of students of Technische Universität München had the opportunity to conduct their final theses within a hands-on project in the Ecuadorian rainforest. Focus was put on fresh and wastewater as well as electricity supply. The latter will be specified by a feasibility study on micro hydropower that was done during a 2-week stay in the village of Yuwientsa. The results were presented and discussed with students from Quito in the framework of a "seminario transatlántico" at Ecuador's oldest and greatest University – Universidad Central del Ecuador.

Yuwientsa is situated in the rainforest about 1 h distance by small aircraft to the nearest town of Puyo in east Ecuador. Up to now, it only had sparse access to electricity although there is an urgent need, i.e., for medication cooling, education, and lighting. There are some PV cells installed and diesel (has to be flown in) generators but by far not enough to cover all basic needs.

The region with an almost closed rainforest area possesses an overwhelming biodiversity and a vivid culture of local indigenous tribes who struggle to preserve their identity and livelihood for their future generations. As this region is also blessed with different kinds of natural resources, there are various commercial ambitions for exploitation. International companies try to get access to believed oil fields or the huge potential of precious tropical wood.

UNESCO declared the region a biosphere reserve to support the sustainable development of the indigenous population. As energy forms the basis for it, a special focus needs to be placed on renewable supply. The goal is to share simple but effective technical solutions in order to enable locals to implement and spread the technology on their own. This can also form an appeal for the young indigenous generation not to leave for the cities but to stay in their communities to protect their forest and therefore play an essential role in global climate preservation. With the implementation of rainforest academies, designed by German artist Markus Heinsdorff, UNESCO provides secondary and tertiary education for the indígenas of the Shuar tribe.

Electricity in the Middle of the Rainforest

The assignment was to find a solution in collaboration with the indígenas to provide sustainable energy supply that is exactly customized to the local needs and on-site conditions. This demands special requirements as robustness and low-maintenance effort of the technology as well as minor ecological impact. External dependencies regarding technical support or fuel supply should be abstained from and low construction and operation cost guaranteed.

Scope of the Project

In order to assess the impact on the local society of the 250 inhabitants of Yuwientsa but also further upcoming project regions, a "social impact assessment" has been conducted according to the suggestions of the UN Centre for Good Governance (2006). The result of the assessed electrification was in overall positive under the constraint of close cooperation and involvement of the local population. The provided electricity demand of approx. 10 kW is mainly needed to illuminate the classrooms and housings. Furthermore, a computer with satellite-based Internet access and a refrigerator for medication need to be supplied. The abundant and reliable availability of water in this region proves the reasonable application of micro hydropower.

During a 2-week stay in the village of Yuwientsa, appropriate installation sites were searched for. It turned out that several layout possibilities are conceivable. A fundamentally important factor was the assurance of flood protection of the installed technical appliances. Several sites were excluded because of spiritual relevance. Finally two preferred sites were identified and surveyed in detail. The first one gave the opportunity of installing an overshot water wheel. The second would use a conventional, i.e., Pelton or crossflow turbine.

Close cooperation and information exchange with the local decision makers as well as with surrounding residents formed the basis of a successful joint project.

Hydrology

The conditions in Yuwientsa are determined by tropical daytime climate with an almost constant mean temperature of more than 20 °C. There is daily cloud cover with convective precipitation. Furthermore, there are distinguished dry (August until November) and rainy seasons (December, January, and May to July).

Surveillance of the hydrological conditions was the first step to assess the feasibility. As there was almost no information on the characteristic water discharges in and around Yuwientsa, the most important fact sources were the experiences and observations of the locals. Nevertheless, some short-term measurements were conducted to get a first impression. After a number of interrogations with people living in the surroundings of the streams, a first insight over long-term hydrological discharges could be gained. Important to mention are the very quick discharge reactions after heavy rainfall as a result of the hilly topography and rather small catchment areas.

In order to assess the seasonal deviations, a measuring gauge was installed at a close river together with the indígenas who check the level daily. But even with all the collected data, the hydrology can only be estimated basically. Through constructional measures, a minimization of negative impact was aspired.

On-Site Approach

The equipment was rather basic and aimed to be flexibly applied in rough terrain. GPS, altimeter, and measuring tape were used for spatial localization; bucket and stopwatch or yardstick for the cross section and leaves as tracers for the flow velocity were the low-tech but sufficient discharge measuring gears. Clear documentation with photos and sketches made later assessment and construction planning possible. Installation potentials were approximated by Eq. 1 with discharge Q and geodetic head H_{geo}:

$$P_{\mathrm{Turbine}} = 8 \cdot Q \cdot H_{\mathrm{geo}}\ [\mathrm{kW}] \tag{1}$$

Using a water wheel, the result will be reduced due to lower efficiency.

Eleven potential installation sites were identified around the village with a power range of 5–35 kW. After a detailed evaluation regarding energy demand, ecological impact, and flood safety, two preferred options were finally chosen.

Water Wheel

First option considered the use of an overshot water wheel at the river Yuwints close to the settlement. A small river drop with a head difference of 2.2 m ends in a bigger basin. The constant (according to the indígenas) discharge of 1.2 m^3/s (measured with tracer yardstick and stopwatch) will therefore offer a permanent hydropower potential of approx. 18 kW. The water wheel with 3.5 m width and 2 m of diameter can be constructed using mainly locally available material (Nuernbergk 2007). The foundation needs to be handled with special caution as it was not possible to further examine the underground conditions. Flood protection forms the most important challenge as an open water wheel is very prone to floating refuse. Therefore, the wheel will be installed in a protected recess with a separately controllable channel inlet. The powerhouse will be placed on an elevated position and driven by a V-belt (see Fig. 3).

Conventional Turbine

The second installation option uses a conventional water turbine with penstock. Best choices are constant pressure turbines like Pelton or crossflow. The latter are especially beneficial with unknown discharge changes and unknown water quality conditions. They possess a sturdy design and low maintenance effort in combination with flexible operation.

The considered site is located at the small river Río Yangunts close to the village center. With a penstock length of approx. 600 m a head of 82 m can be used. The water discharge of around 25 l/s would result in 10–13 kW of electrical power. According to the residents, the water yield is a little fluctuating but constantly available. The penstock alignment is best done along the brook – also in order to avoid air entrapments. The natural water reservoir with a volume of approx. 20 m^3 can easily be used as inlet structure.

Due to logistic but also economic reasons, a PVC penstock is the preferred option. The use of a pipe with 0.125 m diameter – as it is available in Ecuador – will result in a usable net head of $H_n = 58.3$ m and therefore 11 kW of electrical output. The maximum pressure according to hydraulic hammer calculations (Joukowsky equation) is $p_{\max} = 15.3$ bar (Giesecke and Mosonyi 2009).

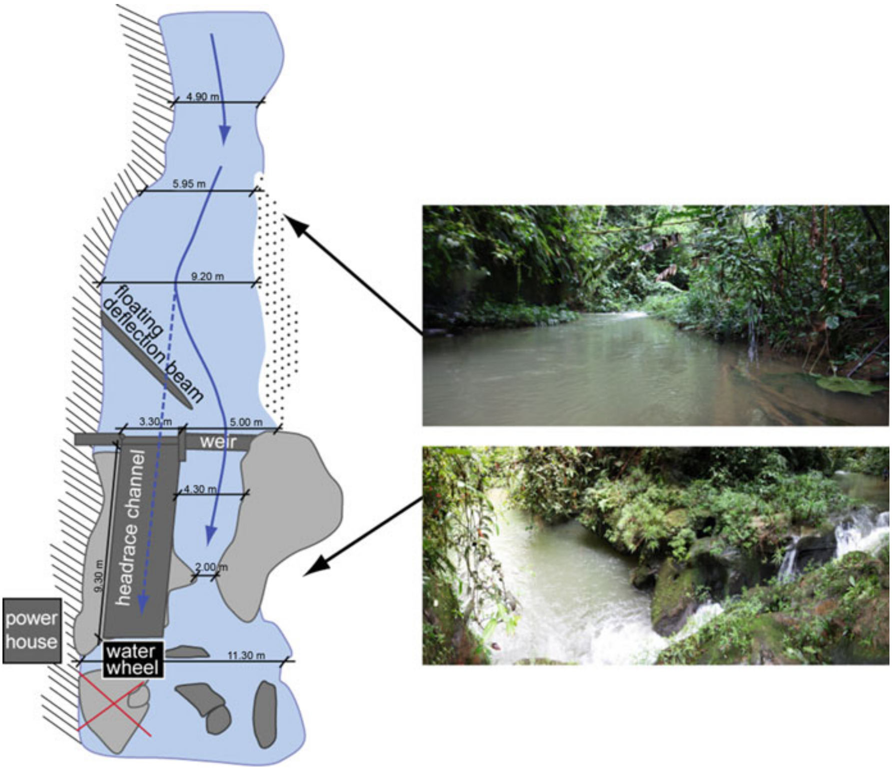

Fig. 3 Plot of the water wheel layout

Electrical Installation

For both installation options, the electricity is distributed through an island grid. For economic reasons as well as the lower freight weight, an asynchronous generator is recommended – even though it has a higher control demand (Williams and Simpson 2009). Basically the produced electrical energy needs to be stored and buffered in batteries.

Outlook

The choice between the suggested options will finally be done by the community of Yuwientsa – also with regard to financing options. Therefore, the results of this study were translated to Spanish and handed over to the village elders. It forms the basis for financial aid requests. Costs are approximated at 30,000 € for the water wheel option and around 50,000 € for the conventional turbine layout (not including labor).

The central concern of the project was and still is knowledge exchange. This is accompanied by the training of hydropower specialists. Close cooperation during

Fig. 4 Indigenous hydropower specialist Tibi with water wheel model (*left*) and in operation (*right*)

the whole stay, permanent consultation, and inclusion of the indígenas made a vivid exchange of experience and knowledge possible for both sites. This formed the foundation of a better understanding of the other's lives (Fig. 4).

Conclusion

Climate change happens. A mean temperature rise of 2 °C is said to be severe but somehow controllable. So if mankind succeeds to limit warming to acceptable temperatures, still any effort has to be taken to adapt to the changing conditions. Any effort means to integrally collaborate worldwide.

Here, a fairly minor approach has been presented. From the reflections that (a) water is global warming's central element, (b) the poorest will be hit hardest, and (c) higher education is the basis of development, an integrated concept of hydraulic knowledge exchange with emerging and developing countries has been elaborated. The importance of the bond between research and higher education – the von Humboldt ideal – has been noticed, and a teaching concept from descriptive fundamental hydraulics to state-of-the-art open-source research and application software for the hydrodynamic determination of flood risk areas has been illustrated.

Finally, the electrification of a village and a rainforest academy in Ecuador using hydropower has been shown. With UNESCO's support the living quality of the indigenous people is improved by satisfying their basic needs and offering higher education; they abstain from moving to cities and protecting their precious land from international timber and mineral oil enterprises. Unfortunately, the hydropower project was only realized in a much smaller scale.

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Climate Change Knowledge Platforms Targeted at West Africa: A Review and a Focus on the New CILSS Platform

T. Ourbak and A. Bilgo

Contents

Abstract

Climate change in West Africa has important impacts due to the low resilience capacity of the majority of the population in these territories. However, on the contrary, in most regions of the world, data and informations on climate change and particularly adaptation are sparse and sometimes difficult to obtain. Nonetheless, scientific state of the arts, policies, as well as tools and funding opportunities and agenda on climate change initiatives are a great challenge for West African stakeholders.

To fill the gap, in November 2012, CILSS/AGRHYMET launched their climate change and sustainable land management platform to allow for easy access to informations targeted at West Africa.

The goal of this chapter is to propose an overview of existing platforms, analyzing assets and differences, and to present CILSS/AGRHYMET platform in this context. Details are given on the platform structure, the "opportunity," "agenda," and "news" parts. A rapid focus on CILSS past and present projects is also presented. Thematic articles concerning essentially agriculture and water, the heart of AGRHYMET's actions, are presented then in the resources part:

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documents, tolls (to challenge vulnerability), and database (AGRHYMET master's students, institutional and individuals, etc.). A presentation of different tools available for download or access on the Web, adapted to a West African use to study vulnerability to climate change and other aspects like mitigation, is made.

Keywords
Platform • Climate change • Sustainable land management • Africa • CILSS • ECOWAS

Introduction

Sahel is often designated as the territory in the south of the Saharan border. It is characterized by low precipitation rates, sparse vegetation, and a rain-fed agriculture mainly based on crops and livestock breeding. Although indigenous knowledge has proved to facilitate adaptation (e.g., Waha et al. 2013), Sahelian countries, among the poorest of the world and also the ones that are the most vulnerable (Niasse et al. 2004), are subjected to drought periods such as the 1973–1974 one or more recently in 1983 (Sarr 2007). Recently, flooding events have been recorded, with important societal impacts (thousands of deaths, Sarr 2010). After the 1973 drought, a few governments decided to create an institution to fight against drought: the Interstate Committee for Drought Control in the Sahel (CILSS). This organization is working to lower the vulnerability of Sahelian countries, this vulnerability being exacerbated by climate change-related phenomena such as temperature increase (Sarr 2012), precipitation variability (Ali and Lebel 2009), and sea level rise.

More and more focus is given to climate change impacts: sea level rise, temperature warming, droughts, extreme events, etc. (IPCC 2007). However, there is a gap between scientific data, research activities, operational needs on the ground, and political action. It has been reckoned that capacity building was necessary to help stakeholders to tackle climate change issues: the way the information is transmitted, popularization processes, and stakeholder empowerment need to be reinforced. The webscape is growing in West Africa, and a lot of UN organizations, NGOs, and institutions are willing to make the information available; but if a myriad opportunities exist for Web users, most of the websites are very specific or, on the contrary, with a large geographical scale with a proliferation of "global" websites not specifically adapted to local West African needs.

In the context of raising attention toward climate change and sustainable development, Africa has around 14 % of the population, but release less than 4 % of greenhouse gases. Thus, although mitigation (i.e., emission reduction with renewable energy or forestry practices), is receiving more and more attention, the main concern for the African population is to be able to be resilient to climate changes (adaptation).

The following text will focus on adaptation, specifically to West Africa, where 13 out 17 of ECOWAS (Economic Community of West African States)/CILSS countries are part of the 49 least developed countries according to UN classification (see http://www.unohrlls.org/en/ldc/25/). It is important to note that adaptation, especially in West Africa, is a transversal topic covering both climate change and desertification under the United Nations negotiations. The CILSS/AGRHYMET website presented here is unique in the sense that it addresses topics related to both UNFCCC (United Nations Framework Convention on Climate Change) and UNCCD (United Nations Convention to Combat Desertification).

The Climate Information Knowledge Gap

Since 1992 and the Rio conferences, environmental issues have raised more and more attention. In particular, climate change has drawn a lot of attention, notably because of IPCC's successive reports, alerting the world on the potential impacts and effects of a changing climate on various sectors (health, economy, environment, etc.).

Most attention has been recently focused on the lack of information available for both policymakers and nonspecialists (media, civil society). The latter is particularly effective when looking at Sahel and West Africa. For instance, the 1970s and 1980s presented noticeable drought periods, which had impacts on the population (food security, livestock issues, water shortages, etc.).

Sahelian governments (up to 13 countries are part of the CILSS in 2013) joined efforts in order to work for food security and sustainable environment. Although data do exist on climate and also on land management, there is a gap between stakeholders and data users.

Overview of Existing Informations

The World Wide Web had been a revolution for the diffusion and access to information. Nowadays, a lot of websites are focused on climate change and particularly, in the context of this chapter, climate change adaptation.

Table 1 summarizes some of the major available websites.

The main feature concerning Table 1, which is not an exhaustive and complete panel of existing efforts available, is that a lot of websites have a global approach. The first website is the only one targeted at West Africa. The West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) is very specific, as it is dedicated to training and research, with PhD and master's programs. The next 5 first platforms presented in Table 1 are dedicated to the whole African continent, and the Web user could find a lot of very useful informations such as updated newsletters and detailed documentation on specific topics. The other websites presented have a worldwide view and, again, bring to the table several crucial informations (the World Bank website presents climate situation nationally, for instance); many specific tools are presented that could be used by policymakers as well as development practitioners on the ground (e.g., methods to mainstream

Table 1 Snapshot of existing platforms

Name and website link	Principal organization/institution/program	Geography	Thematic	Plus	Minus
WASCAL (West African science service center on climate change and adapted land use) https://icg4wascal.icg.kfa-juelich.de/	Federal Ministry of Education and research. Center for Development research (Univ. Bonn)	Ten West African countries	Climate and weather, landscape dynamics, agricultural systems, markets and livelihoods, risk management	Focus on research	Site under construction, English only
Réseau AfricaAdapt (consortium) http://www.africa-adapt.net/	ENDA (Environnement et Développement du Tiers-Monde), FARA (Forum for Agricultural Research in Africa), ICPAC (IGAD Climate Prediction and Applications Centre), IISD (Institute of Development Studies)	Africa	Adaptation (thematic or geographical entries)	A real network of people, sharing ideas	Portal could be more dynamic
AAKNet: Africa adaptation knowledge network (UN) www.africa.ganadapt.org	UNEP (consortium of 9 partners)	Africa	Thematic, geographic, projects, knowledge base entries	Dynamic, lot of documents	Difficulties to download in African places, mix of languages (mainly English but sometimes in French)
*Afri*CAN climate (EU) http://www.africanclimate.net/	Funded by UE, coordinated by **WIP Renewable Energies (Germany) with 5 European and 5 African organizations**	Africa	Research, policy, good practices, indigenous knowledge, finance and geographical entries	Filtered parts, practical (e.g., financing guidebook)	Program will end in 2014, not specific to Africa

ACCRA (African climate change resilience alliance) http://community.eldis.org/.59d66929/	Consortium of NGOs	Africa	blogs	Files not regularly updated	Growing community (less than 600 members in May 2013)
Climate change knowledge portal http://sdwebx.worldbank.org/climateportal/index.cfm	World Bank	Global	For development practitioners and policymakers	Easy to use, data and maps accessible	Not focused on a specific region: general approach
WEADAPT http://weadapt.org/	Community (less than 2,000 in May 2013), define as an "open space"	Global	Collaborating on climate change	Innovation such as Adx (climate adaptation options explorer Adx, adaptation layer)	Easy design to get lost for first-time user
CDKN (climate and development knowledge network) http://cdkn.org/regions/africa/	Alliance of organizations (leader: PricewaterhouseCoopers LLP (PwC))			Technical advices, build partnerships (climate compatible development strategies and plan). 3 languages	Only 4 countries in Africa
http://www.undp-aap.org/	UNDP and other UN agencies	Africa	Countries, resources, work areas entries (+newsletter)	User friendly with a lot of technical and political informations	Program finished in 2012

(*continued*)

Table 1 (continued)

Name and website link	Principal organization/institution/program	Geography	Thematic	Plus	Minus
Adaptation learning mechanism http://www.adaptationlearning.net/	Joint effort from main UN agencies + UNFCCC	Global	Based on communities	Interactive map, very diverse entries (from agriculture to workshop materials)	Difficulties in accessing the website (download elements from the map)
Community adaptation based adaptation exchange http://community.eldis.org/cbax/	Community (more than 1,000 in May 2013), launched by NGOs	Global			
The knowledge resources page of UNFCCC adaptation http://unfccc.int/adaptation/knowledge_resources/items/6994.php	UNFCCC (different work streams: Nairobi Work Programme, NAPs, NAPAs, loss and damages)	Global	Databases, publications, LDC portal, newsletters	A complete website from the international climate change negotiations	Portal could be more dynamic and focus on user needs and user friendliness

climate change into policies to climate proofing tools). Most of the websites are user friendly and easy to discover for the nonspecialist while containing targeted documents or informations.

One notes that most of the websites are from international organizations, such as United Nations websites, or NGOs (nongovernmental organizations). It is important to note the United Nations Framework Convention on Climate Change website, very complete, which addresses the outcomes and presents the material of the negotiations. Some websites are project related, such as the Africa Adaptation Programme, which could lead to a potential problem of durability and dynamism once the funding is over. Most of them contain a lot of informations that are user friendly.

A lot of different languages are used in Africa. In Table 1, all the websites are accessible in English and 7 out of 12 in French, and other languages such as Spanish, Portuguese, Arabic, or Deutsch are also available. It is to note that two websites propose translation in numerous languages such as Afrikaans or Swahili. However, some websites propose only the translations of titles and rubrics. Most of the sites are aimed at disseminating information to professionals and not to producers and politicies makers. The forum is a way for users to ask specific questions. The CILSS/AGRHYMET website is doing an effort to adapt the knowledge and science presented, for instance, thematic pages, with simple figures helping the reader to have a better understanding of complex topics.

However, not a lot of governmental websites such as the ones you could find in most of the developed countries exist in Africa. This could bring the issue of the validity of information found for policymakers and governmental stakeholders. For instance, a politician working in health issues could be interested to have access to several informations such as climatology of flooding events or heat waves. This specific example could be translated to many sectors where the information could be very difficult to obtain. We already have had feedbacks from local and national West African agricultural organizations using technical informations provided on the platform. Moreover, although the number of platforms is important, most of them are not specifically targeted at West Africa, although recognized as a very vulnerable region, and bring a large amount of general considerations on climate change.

Presentation of the CILSS Platform

When creating the CILSS climate change and sustainable land management platform, the idea was to create a unique site where one can find diverse informations targeted at West African needs. Figure 1 presents a snapshot of the CILSS/AGRHYMET platform (www.agrhymet.ne/portailCC).

Six parts have been created:

- The NEWS part is the most consulted one so far. It is regularly an updated source for opportunities of training and funding, for example, but also news and agenda.

Fig. 1 Snapshot of CILSS/AGRHYMET platform (July 14, 2013)

For instance, call for grants and application for projects or programs are recorded. Any stakeholder could find a peculiar call for grants and a researcher could have information on a specialized workshop as well as general conference and could find an updated intergovernmental negotiations process; the three rubrics are the unique entry to keep up with what is ongoing for the West Africa Adaptation world.

- The MENU part is a more classical package, with a presentation, informations on teaching activities from the AGRHYMET Regional Center, useful links to navigate the Web, and a presentation of the platform, contact, and a research tool.
- The PROJECTS part presents emblematic ongoing or achieved CILSS projects. This is a unique way to capitalize a multi-project database and to make sure the information is still available even after the end of funding (e.g., the “Projet d’appui aux capacités d’adaptation des pays du CILSS au changement climatique” project was a pioneer and innovative project tackling climate change issues in West Africa, and some of the most important documents produced are made available).
- The THEMATICAL part presents popularized, easy-to-understand access to the following areas of CILSS expertise: climate science, adaptation, mitigation, climate governance, and water management. The climate science part describes

West African climatology, monsoon system, and hydrology regimes and presents the climate change context. The adaptation part describes some generalities that focus on agricultural practices adapted to climate change in a rain-fed context, an irrigated context, and finally a pastoral context. The mitigation part presents several aspects of the mitigation issues for West African countries, such as financing processes and CILSS actions. The climate governance presents the Intergovernmental Panel on Climate Change process, as well as the negotiations under UNFCCC, and focuses on the regional as well as national level of political documents. Finally, the water sector is presented with a special attention drawn on impacts of climate change on water and a few adaptation strategies.

- The RESOURCES part presents several documents such as CILSS documents, national and regional documents (National Adaptation Programmes of Action (NAPAs) (under UNFCCC) but also national action programs (under UNCCD) as well as West African organizations such as ECOWAS policy papers), synthesis documents and also tools and products (mitigation, impacts and vulnerability, sustainable land management, etc.), database on CILSS students, and finally scientific publications. It is sometimes a unique way to have access to such documents.
- The FORUM part is a very new part and is trying to bring experts to discuss various topics. As an example, the first topic is the cost of adaptation in rain-fed West African agricultural systems.

This site has been launched at the end of 2012. So far, 7 months after launching the report, it has received more than 30,000 views. The question of language is crucial to reach a maximum of users. At the beginning, we have produced only a French version. However, noting that around 15 % of our users are connected from English-speaking countries, we have added an English translation to reach more users. However, CILSS is willing to translate the website in Portuguese to cover the official languages of the CILSS/ECOWAS region. It is important to note that a mean of 5 min is spent by every user and that around 40 % are regular users (i.e., which come back regularly to the website) visiting 3 pages on average.

Concerning the geographical origin of the Web users, the vast majority are connected from African countries, namely, Niger, Burkina Faso, Senegal, Togo, Benin, Ivory Coast, and Mali, whereas less than 15 % originated from developed countries (France and the United States).

Conclusions

While climate change impacts are widespread all over the planet, a lot of attention has been given in order to make information accessible to Web users. However, although very vulnerable, the West African region has not received a lot of attention specifically focused on West African regional circumstances. After reviewing the existing platform, the chapter has presented detailed informations related to the CILSS climate change and sustainable land management platform. The next step to improve the platform is to work with more focus on user needs. The CILSS is willing to start a dialogue with different types of stakeholders in order to publish informations useful for the most part. A fine analysis of the utility actual users are making of individual pages is in progress and should flourish the development of new informations. It is expected to produce a questionnaire and to send it to Web users, to produce more demand-driven information. The forum part should be more active, and a work is also under progress by CILSS experts in order to determine the most effective way to make experts react to posted articles. Finally, the network should be strengthened inside and outside West Africa in order to transfer knowledge and to spread out good practices and tools, for example, by presenting the platform to international fora, such as the Conferences of the Parties of the United Nations Framework on Climate Change Convention (UNFCCC) or other relevant fora, but also by having a communication strategy to "spread the word," by e-mail lists, newsletters, and interaction with other platforms.

The lesson learned is that the strong demand for information posted on the platform is a real challenge. While climate change issues are getting more and more attention, there is room for information sharing and dissemination of all kinds of informations to those who need it; however, there is a lot of overlapping and much attention is done to specific topics or areas. Although not directly linked to it, this website is part of a broader Nairobi Work Programme on impacts, vulnerability, and adaptation to climate change ongoing under UNFCCC. An incoming challenge will be to make this platform more interactive, with a discussion forum, and the possibility for the Web users to ask for specific questions to the community and for specific topics to be treated in the website. The first feedbacks we had are encouraging, and counting methods teach us that the vast majority of users are coming back regularly. The next step is to better understand their needs (so far, the majority looks for opportunity) as well as attracting new users. This website is one of the milestones in building a common response to climate change and building a more resilient Africa.

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Climate Resilience in Natural Ecosystems in India: Technology Adoption and the Use of Local Knowledge Processes and Systems

Prakash Rao and Yogesh Patil

Contents

Abstract

Excess water and energy consumption, unplanned urbanization, and consumption patterns may form the key indicators of future climate mitigation. Entrepreneurship-based ventures in energy and agribusiness with strong community focus coupled with traditional knowledge processes can go a long way in strengthening community systems. The chapter proposes an approach to enhance

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the coping capacity of the community, and vulnerability reduction is proposed through use of technologies and local knowledge systems. Combining traditional knowledge systems with new research ideas and development of innovative technologies can provide a suitable adaptation response in the face of adverse climate impacts. The use of innovative technologies like geographical information systems, software-based weather systems, low-cost and decentralized technologies, as well as industrial symbiosis as a concept is therefore proposed. The chapter proposes a paradigm shift in the way government programs are conceptualized and implemented through innovative technology diffusion and industry action. The solutions suggested in the chapter have significant benefits for rural communities and ecosystem-dependent stakeholders with a focus on integration of natural resource base and socioeconomic concerns of local communities.

Keywords
Climate adaptation • Communities • Technology • Traditional knowledge • Industry

Introduction

In recent times, at least in the last 200 years, humanity has made rapid strides in economic growth across the world. While an agrarian economy might have remained a major base and perhaps so even today in many parts of the world, the desire to expand horizons and explore vast frontiers has led to creation of an industrialized economy. Such an economy which brought about huge economic progress to millions of people through better living standards, access to communications, transport, health care, education, etc. also meant that there were significant impacts to the local environment over several decades.

The past few decades have perhaps been one of the most tumultuous phases in the development of humanity in the context of three important sectors, namely, industrialization, sociocultural values, and the environment. While the first two sectors have seen phenomenal increase in intellectual thought process leading to innovation and creative desire to excel, the third sector, namely, the environment, has perhaps borne the brunt of the rapid progress made by industrialization.

In the 1900s most of the developed group of nations moved ahead rapidly, through rapid industrial growth to create a welfare system within their polity. The European Union and United States formed the largest group of nations where rapid industry growth was an indicator of progress and growth. However in the Asia Pacific region and in particular countries like India which were under the rule of foreign nations or were just about emerging from colonialism in the early half of the 1900s were seen to lag far behind in terms of industrialization. In India this could be divided as preindependence era and postindependence era. This chapter, while tracing the overall historical perspective of environmental issues, a factor in corporate and societal governances, focuses on some of the rapid stride and changes made in the last few decades in postindependence India.

The postindependence India has also been the period when much of the world's efforts have gone into building institutions of governance across the world ranging from political, economic, social, and environmental paradigms. Education has played a key part in driving the paradigm of growth across these sectors in the past 50 years or so. Since 1947, independent India has had a major thrust towards industrialization, and building the country's granaries to fulfill the needs of its citizens was a key priority.

Climate Change: A Global Environmental Threat

Changes in precipitation, temperature, glacial melt patterns, and sea level rise are being seen as increasingly affecting the world's ecosystems and natural resource base. The Intergovernmental Panel on Climate Change (IPCC) has provided clear evidence of the impacts of climate change on biodiversity and the increasing vulnerability of some critical ecosystems and consequences for livelihoods of people. The recent erratic weather and monsoon patterns in the Indian subcontinent coupled with climate variability and rise in the incidences of extreme events like cyclones are major threats to the ecosystem, e.g., low-lying islands, some of which are already facing partial submergence resulting in shoreline changes (Dinesh Kumar et al. 2007). In places with high human density and dependent on an agro-economy, such changes have often led to adverse impacts on the local eco-diversity. Ecosystem-dependent communities are particularly vulnerable where single-crop agriculture, fishing, and harvesting of other local resources are practiced. These in turn could be adversely affected by changes such as sea level rise, increase in salination, changing patterns of rainfall, and increase in moisture content in the atmosphere leading to increasing incidences of vector-borne diseases, e.g., fishing communities along the coastal region are at increased risk due to reduced fish catch as a consequence of warmer seas.

The Decade of Sustainable Development

The early 1990s perhaps can be termed as a landmark decade in the history of humanity as it was the realization of some of the most important global environmental threats which were reviewed by the United Nations. It was also one of the decades when the entire issue of sustainability as a tool of corporate business practice became a reality with the involvement of major industry players, civil society, academic bodies, and the United Nations. In 1992, the United Nations Conference in Rio de Janeiro, Brazil, also popularly known as the Earth Summit (www.un.org) established three major international conventions namely:

- The Convention on Biological Diversity (CBD)
- The United Nations Framework Convention on Climate Change (UNFCCC)
- The United Nations Convention to Combat Desertification (UNCCD)

The UNFCCC was considered one of the most important conventions established to fight the global threat of climate change through mitigation and adaptation efforts. While corporate social responsibility as an ethical business practice was in prevalence for a few years, it was only after the establishment of the UNFCCC and other industry bodies that environmental management and sustainability practices began to be seen by business and industry leaders (Adams et al. 2011) as an important part of their business operations. The mitigation efforts under the UNFCCC also provided for various market mechanisms like the Clean Development Mechanism (CDM) and Joint Implementation (JI) and emissions trading as a means to get the corporate world into meaningful involvement on sustainable development activities (www.unfccc.int).

Impacts of Climate Change on Ecosystems and Processes

Climate change is expected to have a series of impacts on India's natural ecosystems like water, agriculture, coasts, mountains, and forests. According to the Fourth Assessment Report of the IPCC (2007), some of these impacts are likely to be felt across a range of systems causing severity of damage for most vulnerable ecosystems.

Water

Climate change is likely to have impacts on the hydrological cycle with underlying impacts on rainfall, increased precipitation, river flows, increased glacial melt runoffs, decreased groundwater, rise in flood-related events, etc. Field initiatives have shown the rapid changes occurring in the Himalayas in retreat of key glaciers by various agencies (WWF 2005; Rao et al. 2009). The scientific community has developed models linking temperature rise and glacial retreat to changing river flows. Future scenarios addressing subsequent impacts on freshwater availability for agriculture, hydropower generation, etc. are of critical concern. This has implications for regional water, food, and energy security in the South Asian region.

Agriculture

The Indian agriculture economy has been typically weather and monsoon dependent and therefore is vulnerable to climatic variability each year. The presence of several agroclimatic zones with a diverse range of crops and grains has resulted in severe dependence with impacts on soil and crop processes. Changes in freshwater supply in the perennial rivers will affect agriculture productivity across different zones. Increases in temperature and water stress are expected to lead to decline in crop yields up to 30 % and changes in phenology and time of growth. For the Indian economy, this could lead to increasing demand for food production, increased competition for land resources, deterioration of agri-environments, scarcity of water resources, and changes in weather conditions. Recent simulation studies on crops indicate a decrease in yield of crops as temperature increases in different parts of India, e.g., for a 2 °C increase, rice yields could decrease by about 0.75 t/ha in the high yield areas. The loss in farm-level net revenue will range between 9 % and 25 % for a temperature rise of 2–3.5 °C. The total food grains production in the country rose from 50 million tonnes – 1950s – to 210 million tonnes by the turn of the century. Food security is under stress largely due to increase in population and demands for energy and freshwater.

New management practices are seen as an adaptation response (Rao 2010). Complex agroclimatic conditions make such practices difficult with low technological and financial adaptability of the community. At existing rate of growth, increasing temperature and more variability of precipitation will put 50–120 million more people at risk of hunger and food prices likely to show an upward trend throughout the global economy. In India, combined effects of poverty, water scarcity, less predictable harvests, and climatic changes are most likely lead to increased conflicts. The rate of growth of agricultural production has been the lowest since India gained independence, from after 1991 till the present. In such a circumstance under severe climate stress, there could be reduced food grain and agricultural production with low per capita availability of food grains.

Adaptation responses and strategies to tackle climate-related stresses could take the shape of climate-smart knowledge processes like:

- Educating farmers in appropriate energy-conserving farming techniques
- Provisioning of seeds of crops that could withstand variable weather conditions
- Use of drip irrigation in place of flow irrigation and enhanced water use efficiency
- Practicing participatory integrated watershed development programs
- Facilitating farmers in developing suitable markets for their produce, and getting a remunerative price
- Concessions or special market outlets or price support
- Production management and practices

At policy level, linkages to the National Mission on Sustainable Agriculture, the National Water Mission, the Integrated Energy Policy, the National Horticulture Mission, and the National Rainfed Area Authority could be explored to address adaptation responses.

Benefits of Developing Localized Knowledge Processes for Society

While there are many facets to developing solutions for climate change in the area of agriculture and coastal ecosystems, there are clearly incremental benefits to society and ecosystem-dependent communities in using technology-based knowledge processes. This could include both individuals and enterprises whose core business is dependent on climate factors. The use of ICT-based solutions also has shown that developmental issues can be addressed on an equitable and sustainable basis where economic, social, and environmental parameters are considered as central to the economic prosperity of society. The role of ICT and agri-retail innovation in rural Indian markets can be seen as a form of climate adaptation for the agribusiness sector.

Apart from agri-related interventions, climate-smart knowledge processes also play a key role in watershed management and the involvement of civil society. The sustainability practices followed by the Indian business conglomerate ITC Ltd. is a case in point where several watershed initiatives have been implemented across arid and semiarid regions of India through collaborative initiatives between industry and civil society groups. Along with water, the role played in the use of efficient energy systems is equally important in developing a sustainable business operation. The importance of decentralized energy generation technologies like biomass power in agricultural markets and wind energy in coastal systems are of great significance.

Information and Communication Technologies for Building Knowledge Processes

In recent times, many global environmental changes have increased the vulnerability of its ecosystems and people. Two of the most sensitive ecosystems in the Indian subcontinent, namely, the coastal region and the Himalayas, are under tremendous pressure from a wide range of biotic and abiotic pressures leading to increased stress to the natural ecosystem and livelihood of people. The increased pressure from resource scarcity in such critical ecosystems often causes a severe imbalance to the economic growth and livelihood patterns of local people and regions. This has long-term implications for sustainability of a region's diversity from environmental, social, economic, and technological perspective. The use of information and knowledge-based systems is a step in understanding some of the dynamics of such complex ecosystems and can greatly contribute to the mitigation efforts of environmental stress (Rao and Patil 2011). Increasing use of technology also means that there needs to be a holistic approach to building capacity of all levels of stakeholders to understand some of the techniques for adapting to changing environmental conditions. This included recent advances in developing sciences like industrial ecology which are shaping the development of integrated industrial centers with high levels of interdependence, thereby providing an alternate adaptation action plan to climate change and low carbon development.

Coastal Systems

The use of information and communication technologies has greatly enhanced the resilience and adaptive capacity of the coastal ecosystem. Studies by researchers in the low-lying coastal region of the east coast of India have tried to introduce various state-of-the-art technologies to understand the local systems better. A comparison of satellite data from 1998 to 1999 showed that some of the islands in the Sundarbans delta in West Bengal, India, have undergone severe erosion of about 3.26 km^2 (Kumar et al. 2007). International conservation organizations like the World Wide Fund for Nature (WWF) have helped bring technology closer to the needs of local communities in order to ensure that the tools and technologies can act as an aid to quantify the extent and nature of the development change to develop sound and sustainable land-use practices. Deltaic regions, like the Sundarbans, experience repeated occurrence of cyclonic storms and depression, and communication tools like early warning systems need to be strengthened to increase adaptive capacity. The WWF Climate Adaptation Centre at Mousuni Island in the Sundarbans is an example of building local knowledge for local communities. This is being achieved by integrating academic, industry, and civil society involvement in helping to bring out natural solutions and helping local communities towards sustainable development against adverse impact of climate stresses. Setting up of these early warning systems is an excellent example of addressing disaster risk reduction from a short-term and a long-term perspective. The use of high-resolution remote-sensing technologies has also helped to get a better understanding of coastal zone dynamics and developing response mechanisms. A recent study using high-resolution digital elevation model data and importing more than 80,000 GPS point data sets (Loucks et al. 2010) in Bangladesh Sundarbans suggests that an expected sea level rise of 28 cm above 2000 levels is likely to severely impact the remaining resident population of the Bengal tigers in the Sundarbans ecosystem.

Agriculture Systems

One of the major sectors which drives the economic activity of a large developing nation like India is agriculture. Much of India's agriculture economy is monsoon dependent, and rural poor and farmers living in the rainfed regions are vulnerable to the variability of the monsoon leading to either excess rainfall or drought-like conditions. The limited resources at the disposal of the rural communities coupled with high level of climate risks identified are a threat to food security, livelihood, and economic prosperity of local communities. Scientific institutions and civil society organizations have therefore been trying to design appropriate coping strategies and mechanism aimed at building a sound adaptation framework to meet some of the threats.

While technology-driven processes like low-cost water-harvesting solutions have their benefits, it is important to first understand the needs and perception of the farming community on the importance on climate change and its impacts on agricultural productivity as well as current adaptation measures being taken up. Under the Government of India's All India Coordinated Research Project on Agrometeorology, a recent survey found that about 70–100 % of farmers had prior knowledge about climate change-related issues. Enhancing rural livelihoods option in rainfed regions in remote and inaccessible terrain like the Himalayas requires innovative technology interventions to enable rural farming communities to address future impacts of climate-related stress. Institutions like the MS Swaminathan Research Foundation, Chennai, India, have pioneered the concept of a village knowledge center in several states across India. These act as resource centers which provide information on local weather forecasting through weather-based agro-meteorological observatory services and crop management practices through Internet kiosks.

Local Knowledge Centers of Farmers

In the state of Andhra Pradesh, India, village-based knowledge centers have been developed where science-based ICT tools have been used to predict the variability of drought-like conditions and micro-level preparedness against drought. The International Crops Research Institute for Semi-Arid Tropics (ICRISAT) with assistance from the Government of Andhra Pradesh have developed a low-cost ICT tool in eight villages aimed at providing detailed queries about local agricultural and weather patterns to village communities through the use of a desktop-based system connected through an Internet hub. A local NGO coordinates these rural knowledge centers through maintenance of the records of responses and solutions provided by technical experts (Sreedhar et al. 2009). The rural knowledge centers have also helped build capacity for local women to undertake their own weather measurements of rainfall temperature. Generation of local-level drought vulnerability maps using GIS-based color-coding mapping tools has helped raise awareness about drought impacts in the region. Community perception about past weather patterns and drought vulnerability assessments is a key component in developing a knowledge-based adaptation practices besides useful use of technology and communication tools. ICT tools at community level will ensure availability of critical information at the right time apart from getting a better understanding of future climate risks.

Industrial Ecology

For most developing countries, economic development has been the issue of top priority as a machine to enhance social prosperity. In the process, eventually for the sake of development, the environmental protection/conservation part was left far behind (World Bank 2000).

In the light of the above background, the present integrated program at symbiosis decided to introduce a new integrated industrial planning and management mechanism in its curriculum. “Industrial ecology/symbiosis/ecosystem” is one such emerging concept in the evolution of environmental management paradigms (Ehrenfield 1997) and springs from interests in integrating notions of sustainability into environmental and economic systems (Ehrenfield 1997). The concept of industrial ecology was first introduced by Frosch and Gallopoulos in 1989 (Heeres et al. 2004), and since then industrial development has entered a new perspective of production and process system. Industrial development thus should resemble the natural ecosystem because, in such a system, energy and resources are optimally used and wastes are absent. In contrast to the earlier viewpoint, industrial ecology considers industrial waste or any other waste (both hazardous and nonhazardous) as an "economic resource" (Ehrenfeld and Gertler 1997; Itankar et al. 2013), which, upon reducing, reusing, and recycling, and recovering means greater profit to the industries/companies in that ecosystem. Industrial symbiosis is designed such that industrial areas are developed mimicking a natural ecosystem (Garner and Keoleian 1995). Natural ecosystems are self-contained and self-sustained and generate zero waste through complex interactions of food chains. Industries are visualized as interacting systems rather than isolated components in a system of linear flows. Waste materials and energy emanated from one source are used as feedstock by other (life cycle approach – cradle to reincarnation). Thus, the model of industrial symbiosis or eco-industrial park (EIP) in developing and underdeveloped countries would have an opportunity to manage their waste to become sources without much investment in the technology of waste management (Bhat et al. 2012; Patil 2012). It will also (a) help industries to improve their environmental performance and strategic planning and will become more competitive; (b) help local communities develop and maintain a sound industrial base and infrastructure without sacrificing the quality of their environments; and (c) help local, regional, and national government to formulate policies and regulations in order to improve environmental protection with simultaneous building of business competitiveness.

One example of industrial symbiosis/ecosystem being practiced in India is at Naroda Industrial Estate (NIE), Gujarat, which was established in 1966 by the Gujarat Industrial Development Corporation (Hauff and Wilderer 2000). This estate is spread across 30 km^2 and consists of 700 companies, which mainly include chemical, pharmaceutical, dye and dye intermediate, engineering, textile, and food production units. Naroda Industrial Association (NIA), which was formed by 80 % of the companies, has founded a charitable hospital and a bank, has constructed a common effluent treatment plant (CETP), and has also planted more than 30,000 trees. NIA and the local bureau of the Confederation of Indian Industry (CII) took up the leadership role by creating the industrial ecology networking in NIE. This began with a baseline survey of NIA members by identifying common environmental problems and focusing primarily on materials, water, and energy usage. NIA convened open meetings in which the companies explored their needs, using a broad eco-industrial network framework as proposed by Rosenthal and Musnikow (2003). This exercise resulted into four priority projects – namely, recycling of spent acid, recycling of chemical gypsum, recycling of chemical iron sludge, and reuse/recycling of biodegradable waste. These projects after its successful implementation resulted into several benefits like conversion of waste products into value-added products for its possible recycling in industries, reduction in transportation cost (logistics), provision of new jobs, reduction in waste disposal cost, reduced demand for natural resources, saved landfill areas, improved profit margin of the industries, energy savings, and several others. Immense success in the first four projects triggered the development of the fifth project in the later stages, wherein 15 ceramic firms came together and invested in ceramic testing laboratory, thereby assuring cleaner production. Thus, the industrial ecology initiative at NIE had clearly demonstrated over the years that the collaborative approach of all isolated companies can effectively improve their environmental and financial performances (Hauff and Wilderer 2000). Other than NIE, there are few other examples of industrial symbiosis happening in India like Tirupur textile sector, Tamil Nadu tanneries, Tamil Nadu paper-sugar complex (all three in the state of Tamil Nadu), and Calcutta foundries, West Bengal (Bain et al. 2010; Erkman and Ramaswamy 2000). It has not escaped the authors' attention that an excellent example of agro-based industrial symbiosis does exist at Warananagar, District Kolhapur, located in the southern part of Maharashtra. This industrial symbiosis has a networking of sugar, distillery, pulp and paper, and dairy industries along with the process like aerobic composting, biogas generation, and agriculture system. However, the Warananagar industrial symbiosis has not been documented so far.

Future Trends

The need for continuous monitoring of ecosystems necessitates the availability of state-of-the-art technology and tools apart from regular capacity building of manpower to use the technologies (Rao 2010, Rao and Patil 2011). Various ecosystems have their own inherent limitations for use of ICT-based tools. It can be said that though there have been many studies conducted on most of the agro- and coastal ecosystems, the lack of baseline data poses as a major limitation in documenting continuous records of climate characteristics and meteorological observations. These are particularly relevant when agribusiness and coastal industries like aquaculture are heavily dependent on adverse climatic conditions. Also, complex interaction of spatial scales in weather and climate phenomena in mountains is not given sufficient importance at most of the times. Therefore, future content development in management education should incorporate knowledge processes that combine emerging technological tools and their role in assessments of climate risk from a business angle. Course curriculum could include:

- Information (improved regional forecasting, local community ICT-based knowledge networks)
- Insurance (innovations in micro finance, weather risk insurance products)
- Technology innovation and diffusion (improving efficiencies for agri-energy linkages), e.g., efficient pump sets in irrigation, captive power generation from agriculture waste, biogas, biodiesel, etc.

In agro-based ecosystems, the use of ICT tools is relatively less complex as it does not entail large investments, and monitoring of weather parameters can be undertaken with low-cost methods and solutions.

The need of the hour is to make use of modern tools such as satellite technology and weather stations and use the results for policy formulation on adaptation issues for the different ecosystem regions as well as catchment or watershed areas which are dependent on them. A multidisciplinary approach is required to integrate the ecosystem research in various sectors and across different stakeholders in order to promote sustainable growth models.

Technology interventions require a paradigm shift in bringing societal benefits in the face of environmental stresses. While there have been some good examples of technology-academia-civil society interface in this direction, a series of action-oriented policies and plans needs to be developed towards creating low-cost technology models in the area of solar power, LED lighting systems, water technologies and distribution services, etc. These could be embedded in the policymaking processes of local governments with the support of various technology providers and inputs from grassroot agencies and NGOs. The concept of providing efficient, reliable, and affordable technology-based services will eventually bring the state-of-the-art tools at the doorstep of large sections of society.

The tremendous growth in telecommunication technologies has seen an increased economic growth and prosperity across many parts of the world. In countries like Bangladesh, the concept of Grameenphone has helped empower some of the rural populace to enable them to move into the mainstream of society. In India, such a model could possibly be tested in key rural districts where access to communications and related services is often a major barrier for development and economic growth. Although the advent of mobile telephony has been seen as a game changer across many parts of India with a subscriber base of over 900 million, the lack of Internet-related services as a tool for social progress is still a problem.

Future research trends are likely to focus at developing and implementing low carbon technologies particularly in the renewable energy sector. Decentralized rural energy generation from solar and biomass power is being seen as solutions to a sustainable future. The recent National Action Plan on Climate Change by the Government of India released in 2008 provides clear focus towards sectors like solar energy, energy-efficient technologies, and increasing capacity of all levels of stakeholders by strengthening their knowledge domain.

The decades of the 1990s and 2000s are perhaps seen as a turning point not only in India's economic growth curve but also heralded a change in global understanding of business growth through increased market-based investment across several regions. In the context of business and industry involvement in sustainability and environmental standards and compliances, this can perhaps be termed as a transition economy considering that many technologies and regulatory structures are yet to be developed across these regions particularly in emerging economies. The opportunity of setting up sunrise industries in renewable energy, hybrid transport and mass public transport systems, waste to energy technologies, water distribution systems and services, low-cost technology diffusion across rural markets, and ICT-based innovation can be major markets for businesses to penetrate. However, it is important to note here that much of these industries are likely to expand only if there are adequate safeguards and incentives provided by regulatory institutions to commercialize technologies and services from just a drawing broad stage in research and development laboratories.

Conclusion

The coastal and agro-ecosystems are known to be one of the most productive ecosystems across the world, harboring a diverse range of floral and faunal elements. The range of ecological services generated by these ecosystems has tremendous implications for the well-being of communities and businesses in sustaining local livelihood and strengthening sustainable development of the region. The increasing developmental pressure being brought upon these regions as a consequence of unplanned development and urbanization (Mukhopadhyay and Revi 2009) have already resulted in severe pressures for both local ecology, business and dependent communities.

Future efforts in building the resilience of the local community and the ecosystems through technology-based knowledge processes should take into account a concerted and integrated approach. There is an urgent need by communities, business and industry, academic institutions, scientists, and policymakers to take a closer look at the linkages between local impacts, scientific research, policy interventions, and the larger understanding of using resource conservation technologies and practices for:

Technology and knowledge processes**:**
- Building local and traditional knowledge systems
- Development of resource conserving technologies
- Improved understanding of regional and local climate models
- Build capacity within management institutions, student community on strengthening technology innovation, and community-level practices

Policy level**:**
- Inter-sectoral collaboration
- Improved natural resource management policies and institutions
- Water and energy demand management
- Improved risk management through early warning systems and insurance schemes

A vision-based approach therefore needs to be adopted as a sustainable growth model for society. Ecosystem-dependent communities and local economies need to be adapted for environmental impacts and supporting mitigation advocacy. As part of this process, various stakeholders at multiple levels need to come together to address the issue of climate change and environment security.

- Local – community-level site-specific measures could be developed.
- National – consensus among stakeholders like industry, policy makers and citizen’s groups for national adaptation and knowledge management strategies.
- Regional – synergies among regional associations, networks, and policymakers.
- Global – supporting intergovernmental processes.

In the context of vulnerable ecosystems, some of the stakeholder groups could include:

- Poor and vulnerable
- Ecosystem-dependent communities (agriculture, fisherfolk communities, etc.)
- Decision-making bodies at local, state, and national levels
- Urban consumers
- Technology innovation and incubation groups
- Climate-dependent businesses and groups
- Regulatory groups
- Scientists and academic bodies

The stakeholder groups should also be fully inclusive, such as all genders, all castes, people with physical and mental disabilities, and minorities. A multidisciplinary approach involving several stakeholders on a common platform can stimulate integration of environmental concerns in overall development planning process. Empowering stakeholders through collaboration could take the shape of establishing institutional processes like Gyan Choupals with local civil society organizations and other stakeholders (MSSRF Report 2009). Environmental stress and impacts are still relatively less understood and strengthening capacity through awareness generation is an important part of building resilience (Report of 5th Convention of Grameen Gyan Abhiyan 2008)

Coupled with other activities this involves promoting the role of grassroots-level civil societies through the development of resource centers and creating local knowledge networks to raise the level of local development planning.

Technology development and technology enabled services play a major role in enhancing the resilience and capacity of society to prosper and achieve sustainable economic growth. Much of the future growth of society is likely to be centered on the ability to adapt to these tools and services to the benefit of humanity. The Internet revolution has already seen a tremendous change in shaping global economies, and perhaps the world is now at the crossroads of using other innovative technologies for creating a sustainable society.

The importance of environment as a compulsory element of primary and secondary school curriculum has already been implemented by the Government of India. Strengthening regulatory frameworks and framing policy guidelines across resource-dependent industries and inclusion of new governance paradigms which focus on sustainability will drive the future efforts to develop sound adaptation policies and processes. This will help in developing a governance model and value systems that is driven by sound social, environmental, and economic performance of societal operations.

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Industrial Waste Management in the Era of Climate Change: A Smart Sustainable Model Based on Utilization of Passive Biomass

Yogesh Patil and Prakash Rao

Contents

Abstract

An industrial sector of any developed and underdeveloped nation plays a crucial role in the overall economic development by way of providing employment opportunities, alleviating poverty, and refining quality of life. Rapid industrial growth in developing economies in the last two to three decades has taken its toll

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by causing environmental pollution. Enterprises of small- to medium-scale (SMEs) in South Asian regions are one such highly polluting sector. Toxic and hazardous wastes emanated from this sector have the potential to cause negative and irreversible impact on human health and ecology. It is, therefore, necessary to take appropriate environmental management contemplations to deal with these wastes. Since the problems associated with physicochemical management practices are a manifold, the use of biomass (biological)-mediated mitigation measures seems to be a promising step, and many ideas, concepts, and research are floating around it across the world. The authors in this present chapter discuss two biomass-based case studies from their previous research work and glide over an emerging management thought/concept for green practices in South Asia for a sustainable tomorrow.

Keywords
Climate change • Environmental management • Industrial pollution • Microalgae • *Scenedesmus* sp. • South Asia • Waste biomass

Introduction

An industrial sector of any developed and underdeveloped nation plays a critical role in the overall economic development by way of providing employment opportunities, poverty alleviation, and refining quality of life. The world, in the recent times, perceives region-wide structural shift toward increased industrialization. Emerging economies and many other developing economies are gradually shifting their dependence from the agricultural to the industrial sector, whereas highly industrialized nations are shifting from the industrial to the service sector. Ghani and Ahmed (2009) have reported that in South Asian countries, the share of industrial sector in the last 5 years has increased from 21 % to 26 % of the total output and is expected to grow swiftly in the years to come. Structural shift coupled with substantial growth of the industrial sector in South Asian countries during the last two to three decades has taken its toll by instigating environmental pollution. Environmental problems include those caused by widespread poverty, industrialization, and a change in consumption patterns. The cumulative impact of these two causes has serious effects on urban dwellers; noise, overcrowding, inappropriate design, and stress contribute to the growing psychosocial health problems of many urban dwellers in developing countries (South Asia Environment Outlook 2009). In order to address these environmental problems, in an emerging economy like India, many universities, institutions, and business schools have introduced energy and environmental management-related programs after post-liberalization (Rao et al. 2013).

Pollution of various environmental segments, viz., air, soil, and water, due to the release of hazardous and toxic pollutants has all the potential to cause deleterious impact to human health, ecology, and climate change. If appropriate environmental contemplations are not integrated with the industrial systems, implications could be manifold. It has been reported that the industrial sector, in general, consumes 37 % of the world's energy and emanates 50 % of the world's carbon dioxide (GHG) and 90 % of the world's sulfur dioxide and nearly all of its toxic chemicals. In South Asia, the carbon dioxide emission was estimated to be about 437 million tons by the end of 2000 and is expected to double by the year 2012–2013 (Ghani and Ahmed 2009). SAARC countries together contribute to 6.59 % of the world's total carbon emissions. Current efforts for global environmental protection are mainly confined around large- to medium-scale development projects. However, small-scale operations have been left unnoticed in spite of their high resource intensity, inefficiency, and high levels of pollution load per unit of production. This has created severe environmental problems and pressures at the local level on industries to manage the waste emanated by them. However, high cost of remediating waste is becoming an increasingly sensitive issue in the current scenario. It is reported that around 125 million people are at risk from toxic pollution across 49 low- to middle-income countries (Blacksmith Report 2012). The report for the first time estimates the total global burden of disease attributed to toxic pollution from industrial sites in these countries. It establishes the global burden of disease from toxic pollution as on par with better-known public health problems such as malaria and tuberculosis. Very interestingly, the report has made the first attempt at creating a widespread estimate of disease burden attributable to toxic pollution from industrial sources (Blacksmith Report 2012). This could be attributed to weak policy and regulations, oversight of industries using hazardous substances and thereby emanating it, mismanagement of waste management, poor technology for management, location of industries in populated areas, the lack of skilled operators, human exposure to hazardous and toxic substances, role of SMEs in emitting toxic and hazardous chemicals, limitation of space, financial resources to incorporate best practices, and many more (Blacksmith Report 2012; Patil 1999).

SMEs and Environmental Pollution

There are more than 6 million small-scale industrial (SSI) units in South Asia, and this sector contributes to about 40 % of the total industrial output, besides having a 35 % share in direct exports (Ghani and Ahmed 2009). SSIs also provide major employability and with reasonable equity benefits in terms of distribution of income. A strong SME sector is critical in terms of the goods and services it provides to large enterprises and to informal microenterprises. However, the flip side of SSIs is that they have a lot of adverse effects on the environment (State of Environment, South Asia 2001). Considering the overall growth rate in developing countries, there is a growing need to address the problems of pollution, energy efficiency, GHG emissions, raw material utilization, and health and safety hazards these industries pose. Furthermore, enactment of stricter regulations across the world demands for effective waste management practices. However, SMEs are facing enormous constraints on using eco-friendly technology due to the shortage of capital, technical know-how, underdeveloped infrastructure, weak research and development, and the lack of awareness of the options for pollution control and prevention. Moreover, smaller industrial units have added burden of using age-old and inefficient production processes, thereby resulting into more pollution. A lack of capital investment, skilled human resource, and limited access to pollution control and prevention systems are some of the other problems being faced by these companies.

Some of the heavy-metal-user industries that come under SME sector are electroplating, jewelry units, steel hardening, printed circuit board (PCB) manufacturing, and automobile industries. These industries emanate large volume of wastewaters containing cyanide and metal cyanide complexes and are one of the pressing environmental issues since long time. Cyanide is well known for its inhibition of sensitive enzyme cytochrome oxidase in all living cells (Solomonson 1981). Despite toxicity, cyanide finds large applications in industrial processes as mentioned above. It has also been listed among priority environmental pollutant by US Environmental Protection Agency (EPA). Therefore, statutory agencies across the world demand for its complete removal from wastes prior to their discharge in environment. The total cyanide and metal content in these effluents ranges from 1 to 250 and 1 to 180 mg/l, respectively. In India, the statutory limit for discharge of total cyanide and metals in the inland water body is 0.2 and 0.1–5.0 mg/l, respectively (Santra 2006). Undoubtedly, metal cyanide bearing effluents cannot be discharged in the environment without proper management and treatment.

Conventional Technologies and Their Problems in the Era of Climate Change

There are several physicochemical technologies known for the treatment of cyanide and metal cyanides from the effluents emanated from SMEs like electroplating, jewelry units, PCB manufacturing, etc. One of the most commonly adopted technologies for the removal of cyanide and metal cyanides is alkaline chlorination, and oxidation process is one of the most adopted technologies (Ganczarczyk et al. 1985; Patil and Paknikar 2000). This method of treatment, although effective on free cyanide waste, is not effective in the treatment of metal-bound cyanide complexes (Eckenfelder 1989). There are several known disadvantages which include production of toxic sludge, relatively expensive due to the quantity of chlorine required (Kenfield et al. 1988), increases TDS (total dissolved solids) content of water, and formation of hazardous chlorinated organics like trihalomethanes (THMs) (APHA-AWWA-WEF 1998). In order to keep operational costs as low as possible, frequently effluents are only partially treated to the cyanate phase (Teo and Tan 1987), or in many cases the undecomposed metal cyanides containing effluents are directly discharged without treatment. Other methods for managing cyanide containing wastes include hydrogen peroxide oxidation, ozonation, electrolytic decomposition, etc. However, these technologies are beset with problems like cost-effectiveness and efficacy and require special equipments and maintenance. Therefore, scientists and technologists across the world are focusing on developing novel technologies and strategies for the treatment of such industrial wastes.

Biomass-Mediated Mitigation

In the last couple of decades, use of biomass-based technologies has emerged as one such effective alternative due to its cost-effectiveness, better efficacy, and eco-friendly nature. However, most of the biological management technologies employ bacterial (Patil 1999, 2008) or fungal (Barclay et al. 1998) organisms, which require high nutrient supplementation and moreover emanate carbon dioxide during treatment process resulting to global climate change. Finding an alternative sustainable biological method and strategy for environmental cleanup is the pressing need of time. Numerous research papers are published concerning biodegradation of free cyanide, metal cyanides, and thiocyanate using bacterial (Patil and Paknikar 2000) and fungal species (Barclay et al. 1998); scanty information is available on employing biomass (i.e., microalgae) for the mitigation of cyanide and metal cyanides (Gurbuz, et al. 2004). Microalgae are photosynthetic in nature and have the potential of utilizing smaller quantity of nutrients. Nevertheless, it has an advantage of energy conservation and mitigation of global warming by way of absorbing carbon dioxide. This fact can certainly lead to a paradigm shift in the near future in regard to the implementation of biotechnological solutions to mitigate environmental pollution.

Secondly, most of the South Asian nations being an agricultural countries, easy availability and accessibility of biomass exist on a large scale. Biomass may be broadly classified into live or active biomass and dead or passive biomass which will include plants and plant materials, animals and their parts, bacteria, fungi, algae, organic fraction of municipal solid waste, agricultural waste biomass, etc. There is a huge potential of converting waste biomass into usable energy. However, till date, approximately 1.5–2.75 % of the biomass energy has only been tapped from India (Global Energy Network Institute 2006; Energy Alternatives India 2013). Waste biomass also has large number of applications in pollution control by virtue of their surface charges and being exploited worldwide for the removal of various contaminants from water and wastewater. Moreover, biomass can be used as animal feed once its entire capacity of recovering the target contaminant from waste is over. Another important aspect of biomass is that it is renewable in nature and is capable of growing on diverse range of waste. Since all the countries in South Asia are tropical, biomass production holds the key for its effective utilization and applications. Saini et al. (2012) have also reported the city-based analysis of MSW to energy generation in India.

There has been extensive literature on the GHG emissions of livestock at regional as well as global levels (Bellarby et al. 2013). It is well known that food production and consumption contribute significantly to the anthropogenic GHG emissions, with livestock being a major source (Steinfeld et al. 2006). It has been reported that contributions from livestock is 18 % of the total GHG emissions (Steinfeld et al. 2006). If the entire global emissions are consumed, then these estimates decrease to 16 % (O'Mara 2011). From the futuristic viewpoint, food security and energy supply are the matter of great concerns. It has been documented that livestock (ruminants) occupy 80 % of anthropogenic land use and consume

35 % of agricultural crops (Bellarby et al. 2013). Because of this, such livestock are directly competing with the agricultural crop production for human consumption and the potential alternative land uses, such as bioenergy crop production and nature conservation (Smith et al. 2010). Managing livestock in the future is, therefore, a very critical issue in the debate of food security and land competition.

While the problems associated with physicochemical technologies are manifold, the use of biomass (biological)-mediated mitigation measure seems to be a promising step from the climate change point of view, and many ideas, concepts, and research work are floating around it across the world. The authors in the present chapter discuss two biomass-based feasibility studies from their previous research work and glide over an emerging technological and management thought/concept for green practices in South Asia for a sustainable tomorrow.

Case Study 1

Research Objectives

To employ low-cost waste biomass for the removal of precious metals like gold and silver cyanide from solutions and e-waste (Bhat et al. 2012; Gaddi and Patil 2011; Patil 2012).

Methodology

While majority of the South Asian countries are agricultural countries, the waste biomass from agricultural systems and agro-based industries is abundantly available. Considering this fact, the researchers in their studies employed a variety of low-cost biomaterials procured from diverse source and habitats for the removal of precious heavy metals from waste solutions and electronics. A diverse range of waste biomass was used in the present study and is reported by Patil (2012). These included agricultural by-products, industrial wastes and by-products, solid waste, waste fungal cultures, mixed algal biomass, photosynthetic plants, and activated charcoal as reference materials (Gaddi and Patil 2011). Primary processing of the biomass samples (collection, transportation, washing, drying, grinding) and experimental protocols was carried out as prescribed by Gaddi and Patil (2011). A biosorption study on silver cyanide was conducted by batch equilibration method as prescribed by Patil (1999). The amount of silver cyanide (henceforth referred as DCAG) sorbed at equilibrium, Q (mol/g), which represents the DCAG uptake, was calculated from the difference in DCAG concentration in the aqueous phase before and after adsorption, according to the following equation:

$$Q = V\ (C_i - C_f)/1,000\ m$$

where Q is the DCAG uptake (mol per gram biomass), V is the volume of DCAG solution (ml), C_i is the initial concentration of DCAG (mol/l), C_f is the final concentration of DCAG (mol/l), and m is the mass of sorbent (g).

Results, Interpretation, and Model Development

Detailed results obtained by the researchers during their studies are well documented (Bhat et al. 2012; Gaddi and Patil 2011; Patil 2012). The researchers observed that the optimum Q (i.e., μmol DCAG sorbed per gram waste biomass) of 0.1 mmol DCAG for most of the waste biomass tested were at pH 6.0. Biosorption was significantly decreased above pH 7.0 and increased in acidic conditions. Waste biomass of *Eichhornia* roots (water hyacinth) and tea powder waste were the most efficient biomaterials for DCAG among all the biomass screened. The Q values obtained for efficient biomass were highly competitive and marginally below the Q value of activated charcoal. The optimum pH for maximum DCAG biosorption by *Eichhornia* root biomass and tea powder waste biomass was in the range of 6.0–9.0 and 5.0–9.0, respectively. It is well documented that the process of biosorption is influenced by the solution pH (Paknikar et al. 2003). Experimental controls run simultaneously proved that biosorption was the only operating mechanism for the removal of DCAG from solutions. On the basis of maximum DCAG uptake, *Eichhornia* root and tea powder waste biomass were shortlisted for further experiment of loading capacity. Loading capacity of biomass could be taken as an equivalent measure of binding sites present. Loading capacity value of *Eichhornia* root biomass (9.74 μmol/g) was highly competitive and comparable with activated charcoal (9.95 μmol/g), which was used as reference material. This opens up new possibilities of developing an efficient biosorption technology for the recovery of anionic species like silver cyanide, gold cyanide, and similar other species. The researchers also observed that biomass pretreated with L-cysteine chemical enhances the biosorption capacity. Uptake of DCAG by *Eichhornia* root biomass conformed to the Langmuir and Freundlich isotherm models. Continuous mode study in fixed bed column showed that the service time (breakthrough point) obtained for silver cyanide was 40 h. Thus, it could be concluded from our screening/feasibility studies that *Eichhornia* root biomass was an efficient low-cost biomaterial for the sorption/removal of silver cyanide from solutions.

In view of the above experimental results, Bhat et al. (2012) have attempted to propose a sound strategic model for the recovery of gold/silver using a combination of hydrometallurgical (chemical) and biometallurgical (biosorption) processes. Figure 1 shows the broad strategic framework for recovery of precious metals from waste electronics and industrial wastes. As per this model, the segregated electronic scrap material consisting of gold/silver should first be subjected to hydrometallurgical process using cyanide as a leaching agent. The gold/silver cyanide (leachate) thus formed could then be subjected to biometallurgical (biosorption) process using a low-cost biomass (like *Eichhornia* root biomass), wherein the biomass will adsorb the gold/silver cyanide within an hour's time.

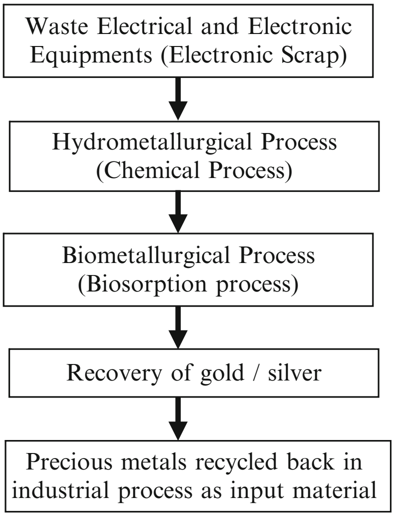

Fig. 1 Proposed broad strategic framework for the recovery of precious metals from industrial waste and waste electronics (Bhat et al. 2012)

Recovery of gold/silver cyanide could be accomplished using a suitable leaching agent. The recovered precious metals then could be recycled back to the industry as an input material, thereby reducing the demand for natural nonrenewable resource. Comprehensive information about the model can be obtained from Bhat et al. (2012).

Case Study 2

Research Objectives

To test the feasibility of treating cyanide and copper cyanide containing electroplating effluent by employing live photosynthetic biomass (microalgae) and development of sustainable waste management model with concurrent mitigation of climate change (Patil et al. 2012).

Methodology

Scenedesmus, a microalga, capable of removing free cyanide and copper cyanide from aqueous solutions was isolated by enrichment technique under alkaline conditions (pH 9.0–10.0). The source of obtaining mixture of algae was the Rankala Lake located in Kolhapur city. *Scenedesmus* sp. was grown in Chu-10 medium for 72–96 h containing 25 mg/l of free cyanide. Downstream processing of the culture was carried out in order to obtain suspension containing 10^6 cells/ml and subsequently used for further experiments. Detailed experimental procedure could be obtained from Patil et al. (2012). The different variables used in this study were as follows: pH (7.0–11.0), temperature (20–45 °C), initial population size (10^3–10^6 cells/ml), and initial cyanide concentration (10–50 mg/l, as cyanide). In all the experiments, one parameter was varied while keeping the others constant. All the analytical methods used in the study were carried out as per the method prescribed by Patil and Paknikar (2000) and Standard Methods (APHA-AWWA-WEF 1998).

Results, Interpretation, and Model Development

Bioremoval of cyanide and copper cyanide by *Scenedesmus* sp. as a function of pH, temperature, and inoculum size is shown in Table 1. It was revealed that degradation of both the cyanide species was significantly affected by the pH of the medium. Optimum pH values observed for free cyanide biodegradation (>99 %) was in the range of 7.0–9.5. In case of copper cyanide, the optimum pH for degradation was 9.5–10. There was no auto-oxidation of copper cyanide above pH 8.0.

It is well known that the cyanide bearing effluents emanated from various metal-user industries have pH in alkaline range (7.5–11.0) (Patil 1999). Biodegradation of free cyanide and copper cyanide in the present study occurred at pH 9.5–10.0. This was because *Scenedesmus* sp. was isolated by carrying out enrichment at alkaline pH in the presence of free cyanide. This result is conducive for the practical use of the process, as very little or no pH adjustment of the effluents may be required. The higher

Table 1 Biodegradation of free cyanide and copper cyanide by *Scenedesmus* sp. as a function of pH, temperature, and inoculum size

	% Biodegradation			
pH	Free cyanide (control)	Free cyanide (experimental)	Copper cyanide (control)	Copper cyanide (experimental)
7.0	>99.0	>99.0	11.2	78.1
7.5	–	–	–	–
8.0	>99.0	>99.0	1.9	81.0
8.5	–	–	–	–
9.0	96.8	>99.0	0.3	95.9
9.5	50.4	>99.0	0	>99.0
10.0	38.9	87.6	0	>99.0
10.5	19.0	78.3	0	59.8
11.0	4.7	39.9	0	5.1

	% Biodegradation			% Biodegradation	
Temperature (°C)	Free cyanide	Copper cyanide	Inoculum size (cells/ml)	Free cyanide	Copper cyanide
20	82.9	73.6	10^3	21.2	18.8
30	>99.0	>99.0	10^4	52.4	28.6
35	86.4	84.7	10^5	76.0	57.1
45	20.7	7.5	10^6	>99.0	>99.0

All the values indicated in the table are the average of two readings; above data is obtained from Patil et al. (2012)

and negligible auto-oxidation of free cyanide and copper cyanide, respectively, in control flasks from pH 7.0 to 9.0 was due to the significant variation of logK value of free cyanide (logK 9.2) and copper cyanide (logK 25.0) (Dawson et al. 1986).

It could be also observed from Table 1 that with increase in incubation temperature from 20 to 30 °C, a concomitant increase in the waste mitigation of free cyanide and copper cyanide occurred. Optimum temperature for maximum biodegradation of both cyanide types occurred at 30 °C. These results were highly significant from the point of view of actual use of the process in tropical countries like India and others, where the average ambient temperature varies between 20 °C and 40 °C. These research findings showed that the *Scenedesmus* sp. used in the present study was alkaliphilic and mesophilic in nature. As far as inoculum size was concerned, complete degradation (>99 %) of free cyanide and copper cyanide occurred with initial population cell density of 10^6 cells/ml within 24–36 h. Therefore, from the process development point of view, it is mandatory to retain maximum biomass in the bioreactor to accelerate the mitigation process.

The researchers observed that biodegradation (>99 % efficiency) of free cyanide occurred within 72 h at initial concentration of 5 and 10 mg/l. As initial concentration increased, longer periods were required. It was revealed that copper cyanide was completely degraded by *Scenedesmus* in 48, 72, and 96 h when the initial cyanide concentration was 5, 10, and 25 mg/l, respectively. These results clearly pointed that the photosynthetic *Scenedesmus* biomass could tackle cyanide up to 25–50 mg/l. This is very crucial as the process developed using this biomass could be immune to shock loads, which are highly prevalent under field conditions in most of the South Asian countries. Presence of the contaminants greater than the normal concentrations in the industrial effluents is normally regarded as shock loads. These shock loads might occur during industrial activities like cleaning, sudden spillages, transfers, decanting, and the presence of acids, alkalis, organic loads, and other toxic substances (Sipma et al. 2010) thereby resulting into sudden increase in concentration.

In further experiments, the authors elucidated the fate of copper from waste solutions during mitigation of copper cyanide using *Scenedesmus* biomass. It was found that S*cenedesmus* sp. utilizes cyanide of the copper cyanide complex resulting in the release of free copper ions. Part of copper gets adhered to the biomass, while the other fraction gets accumulated inside the biomass. The above study clearly points out the fact that heavy metals that are associated with toxic chemical species (like cyanide) are very precious and finite resource (nonrenewable) and therefore could be recovered using biomass (alive or dead) in their suitable speciated form.

Interpretation

From the above results and foregoing experimental evidences, the authors propose a novel biotechnological model from the climate change point of view using *Scenedesmus* sp. as shown in Fig. 2, now summarized.

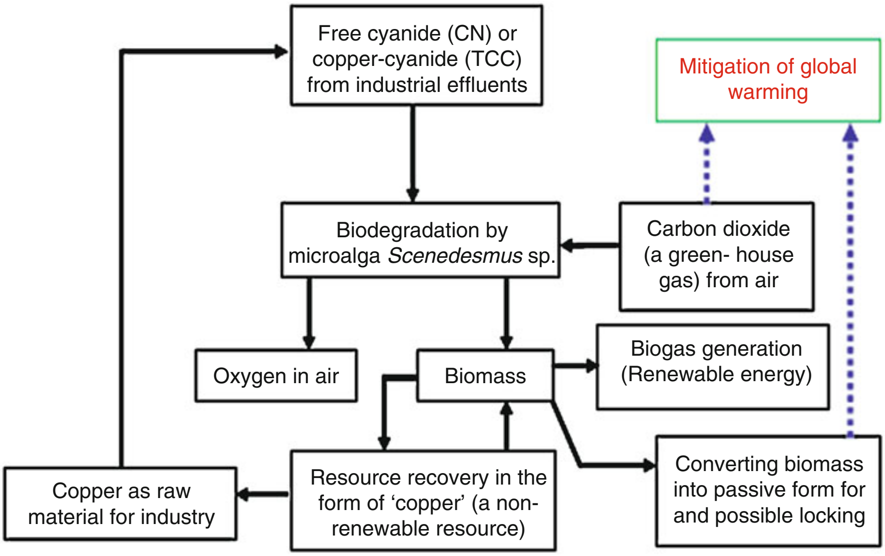

Fig. 2 Integrated sustainable biotechnological strategy using microalgae (Patil et al. 2012)

Inorganic cyanide and metal-bound cyanide (copper cyanide in this case) could be utilized and managed by *Scenedesmus* sp. as the sole source of carbon and nitrogen in the presence of air (oxygen). In turn, carbon dioxide (GHG) from air will be absorbed by alga along with cyanide to build up the biomass with simultaneous generation of oxygen. Surface charges and inherent capacity of biomass will ensure removal of metal from waste solutions (recovery of nonrenewable resource). After metal recovery by a suitable process, biomass free of metal could be employed for biogas generation (energy recovery) or as poultry feed. Moreover, photosynthetic biomass could also be converted into passive form for possible burying in the Earth's crust, thereby reducing carbon dioxide from atmosphere (for this, end-of-life mines can be used). This would ensure mitigation of global warming. Table 2 shows some rough estimates as far as the carbon dioxide capture from atmosphere by *Scenedesmus* species in concerned.

These theoretical calculations are based on the biomass data obtained from the studies carried out by Maraskolhe et al. (2012) and Toledo-Cervantes et al. (2013). From the calculations, it could be seen that the amount of carbon dioxide that would be captured by one large-sized mine would be 0.005495 Gt (i.e., 0.0015 Gt of carbon). In the year 2012, the total global carbon emission from the fossil fuels burning, cement, and land-use changes was 9.7 Gt, i.e., 35.6 Gt of CO_2 (www.co2now.org). Therefore, the amount of carbon locked in the form of microalgae *Scenedesmus* sp. by one mine would be 0.0155 %. Although this figure is only for one mine and small as compared to the total carbon emissions per year, but the authors firmly believe that this could be one of the several ways to combat climate change.

Table 2 Some theoretical calculations of capturing atmospheric CO_2 by *Scenedesmus* species

Parameter	Amount	Comments, if any
Rate of biomass production (dried) per liter	4 g	–
Amount of carbon dioxide fixation per liter	1.4 g	Approx. 35 % of the total biomass production
So for every 1,000 kg of biomass, amount of CO_2 captured would be	350 kg	–
Volume of an end-of-life mine of large size	19,625,000 m^3	Assumption: 100 m depth and 500 m diameter (a cylindrical mine)
Dried algal biomass that could be accommodated in mine (80 % of total capacity)	15,700,000 m^3	Assumption: 1 m^3 = 1,000 kg of dried algal biomass
Therefore, total CO_2 that could be captured by one mine of large size	5,495,000 m^3 (i.e., 5,495,000000 kg or 0.005495 Gt[a])	Algae can be locked in mines after suitable alkali treatment (to raise the pH) to cease biological action
So total carbon locked in one mine	0.0015 Gt	Carbon dioxide converted to Carbon by dividing with 3.67 (i.e., 0.005495/3.67)

Source: Maraskolhe et al. (2012); Toledo-Cervantes et al. (2013); [a]*Gt* gigatons

Recovered metal can further be recycled back to the industry, thereby reducing the demand for the natural nonrenewable resource. Thus, the integrated biotechnological strategy using microalgae suffices the problem of pollution control, resource recovery, and energy conservation with simultaneous mitigation of global warming. In view of the above, the present case study certainly adds to the advancement of knowledge in the field of bioremediation. Furthermore, this novel management thought after further studies could readily be practiced in most of South Asian countries where right environmental conditions do exist in considerable amount.

Conclusion

Both the case studies mentioned above explicitly point out the fact that photosynthetic biomass (like microalga) and the waste biomass from different sources have got immense potential to remediate the industrial effluents containing toxic chemicals with simultaneous recovery of heavy metals (nonrenewable resource). The authors firmly believe that concurrently, the biomass-mediated treatment technologies can also mitigate the climate change by way of using carbon dioxide from atmosphere and utilization of waste biomass which are recyclable in nature. Low-cost treatment technologies also have the advantage of energy efficiency and savings thereby indirectly mitigating climate change. The authors therefore strongly recommend that this emerging and novel management concept could certainly put into practice in most of emerging economies of South Asia for a better sustainable tomorrow.

Although there are several advantages, employing microalgae does have some disadvantages as well. Microalgae require light for its growth which in normal circumstances is only available for 10–12 h during day. Energy inputs are required during night in order to speed up the growth and biodegradation process which might lead to cost escalation. Secondly, alga requires huge space which normally is the constraint, and thirdly, it is a slow grower compared to the other microorganisms (viz., bacteria) in order to accomplish biochemical reactions. At this moment, culturing algae is not economically viable. Drying of algae is also a challenge, which consumes substantial energy and lowers overall efficiency. Currently, algal technology is in its infant stage and not used on a large scale. Despite several limitations, the authors firmly believe that microalgae will certainly play a key role forward to combat climate change.

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Smart Metering and Sustainable Behavior in Low-Income Households in the Mediterranean

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Abstract

Comparison between the EU's 2020 energy efficiency targets and the forecasted energy savings clearly indicates a gap for expected energy savings in 2020. One of the reasons lies in the lack of specific policies for low-income households, which represent about 40 % of Mediterranean households and are considered as *far to reach* through traditional public policies. Due to their complexity, low-income households require innovative financial approaches for implementation of energy efficiency measures. Smart metering has been identified as one of the climate change adaptation technologies which can be used to encourage people in low-income households to become more aware of their energy consumption and stimulate them to change their energy-related behavior. Activities presented in this paper have been evaluated within the EU-funded project ELIH-Med with the objective to identify innovative energy efficiency measures and financial instruments for low-income households in the Mediterranean area. Also, this paper evaluates the impact of customized and adaptive consumption feedback on energy behavior patterns and energy savings in low-income households. Energy and cost saving prediction and verification flowchart are outlined to yield different combinations of suggested smart metering services, which would enable the minimization of households' environmental impacts.

Keywords

Energy efficiency • Smart metering • Consumption feedback • Behavior • Low-income housing • Mediterranean

Introduction

The European Union (EU) has set a primary energy saving target of 20 % below the 2007 projections for 2020 (European Commission 2007). The success in achieving this goal will largely depend on promoting efficient energy end use in households. Many studies have confirmed that decisions and concrete actions of individuals have greater power and effects than capability of municipal administration to interfere in their actions. End-user's (consumer) behavior is a very important parameter for the success of each national energy efficiency policy and related programs. It is necessary that the government efforts on the state level address not only what state or city can do directly to improve energy efficiency but also how the state can promote greater adoption of new and efficient technologies by consumers. According to (Birnera and Martinot 2005), this can come through changes in regulation, taxes, subsidies, access to capital, and provision of trusted information, as well as marketing and campaigning to raise the awareness and encourage consumers to make choices that are both economically and environmentally sustainable. In the present moment in the framework of sustainable and climate-friendly development of urban areas, the most often highlighted problems are efficient spatial planning, efficient and secure energy supply, and efficient public transport. Energy efficiency is a red line, which connects all abovementioned areas.

However, many contemporary policies and instruments for reaching energy saving potential are mainly oriented on technical systems (building envelope, heating systems, electrical appliances), while behavioral changes are addressed only by improved information availability through awareness campaigns. As presented by Gram-Hanssen (2013), user behavior is at least equally important as building physics when it comes to energy consumption for heating, while electricity consumption for lighting and appliances is more dependent on the user behavior than on energy-efficient appliances. Interactions between different parameters that have the effect on households' energy consumption are presented in (Haas 1997). In general, energy consumption in households depends on many different parameters, namely, household structure (dwelling area, number of occupants, etc.), occupant's behavior, technical efficiency of the installed equipment, and climate variables.

In the present economic and financial crisis, the costs for energy and related challenges become even more important, and new and innovative approaches need to be considered in the residential sector where low-income households (LIH) must be specially targeted. Energy efficiency in low-income housing in the Mediterranean (ELIH-Med) project (strategic project within the MED Program, started in 2011) focuses on energy efficiency in the context of EU climate and energy targets for 2020. The LIH represent about 40 % of Mediterranean households and are considered as *far to reach* through traditional public policies (ELIH-Med 2010). Smart metering and its consumption feedback approach can be used for encouraging improvement of end-use energy efficiency and environmentally sustainable behavior in the targeted sector. As pointed out by European Smart Metering Alliance (2010), smart metering adds value to the ordinary utility service, giving better information to consumers and optimizing the use of the demanded power and consumed energy. Smart metering is widely used as a synonym for a system that records energy consumption and other parameters with bidirectional communication between utility and its clients. It implies a new relation model between the utility and its clients, using Information and Communication Technologies (ICT) to interchange information between the utility and the devices installed at consumer's premises.

The majority of people tend not to see or feel the link between their actions (behavior) and the households' energy performance and impact on the environment. Households' behavior has been of great interest to social and psychological scientists as presented in (Abrahamse et al. 2005; McCaley 2006; Faiers et al. 2007; Steg 2008). Also, in many empirical studies, it can be found that individualized energy use information in the form of more informative bills, periodic feedback, and continuous feedback can lead to reductions in energy use. However, from the scientific point of view, it is not clear whether feedback needs to be more frequent to be effective and the sophisticated real-time monitors are more effective than simpler versions (Allen and Janda 2006). On the other hand, as pointed out by Fischer (2008), relevant features of consumption feedback that may determine its effectiveness are frequency, duration, content, breakdown, medium and way of presentation, comparisons, and combination with other instruments. In spite of considerable data restraints and research gaps, there are some indications that the most successful feedback combines the following features: it is given frequently and over a long time, it provides an appliance-specific consumption breakdown, it is presented in a clear and appealing way, and it uses computerized and interactive tools (Fischer 2008). Considering the socioeconomic factors, household income has been found to be a significant determinant of baseline energy use, but not of energy conservation behavior in reaction to feedback (Heslop et al. 1981; Brandon and Lewis 1999; Matsukawa 2004). On the other hand, it is undeniable that human behavior impacts energy consumption and varies from culture to culture (Wang 2011). To evaluate the social dimensions of energy use, initiatives that combine society, energy, and technology in various permutations are needed (Janda 2009).

This paper evaluates the impact of customized and adaptive consumption feedback on energy behavior patterns and energy savings in LIH. Activities presented in this paper have been evaluated within the EU-funded project, ELIH-Med. Several pilot project locations were selected for the installation of different smart metering and advanced consumption monitoring systems with the objective to identify innovative energy efficiency measures and financial instruments for low-income households in the Mediterranean area. Participating Mediterranean countries are Spain, France, Italy, Greece, Cyprus, Malta, and Slovenia. Besides analysis of consumption feedback, supported by different smart metering solutions, the ELIH-Med project also focuses on identifying and demonstrating the feasibility of other innovative energy efficiency measures and financial instruments with the deployment potential relevant to Mediterranean territories and supported by European Regional Development Funds (ERDF).

Reaching EU 2020 Objectives in the Mediterranean Area

In 2008, the share of energy consumption in households was 25.3 % of the total EU final energy consumption (European Environment Agency 2011). While space heating and cooling remains the most significant component of households' energy consumption in EU, electricity consumption associated with the use of electrical appliances increased the most rapidly in percentage terms during the recent years – increase of more than 21 % per dwelling comparing with 1990 (European Environment Agency 2011). According to the requirements of directive on energy end-use efficiency and energy services (Directive 2006/32/EC), each EU Member State had to adopt and achieve an indicative energy saving target of 9 % by 2016 in the framework of the first National Energy Efficiency Action Plan (NEEAP). Despite the commitment and huge policy efforts to boost energy efficiency improvements by EU Member States, the EU is far from reaching its 2020 energy saving target as shown in Fig. 1 (European Commission 2009).

In 2010, after a large and long-lasting consultation with the public, the European Commission presented the *Energy 2020 – A strategy for competitive, sustainable, and secure energy* (European Commission 2010). Within the strategy for competitive, sustainable, and secure energy, the European Commission defines the energy

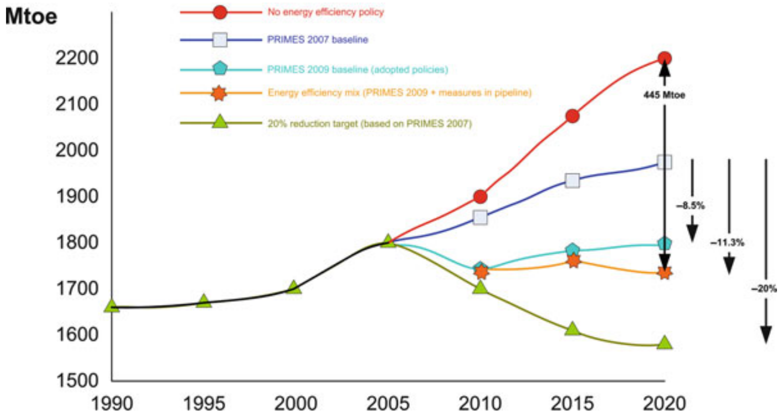

Fig. 1 Energy saving policy gap in the EU countries: development and projection of gross inland energy consumption for EU by 2020 (European Commission 2009)

priorities for the next 10 years and sets the actions to be taken in order to tackle the challenges of saving energy, achieve a market with competitive prizes and secure supplies, boost technological leadership, and effectively negotiate with EU's international partners. The objectives presented in the European Commission (2010) are part of the EU's 2020 strategy and in 2011 posted Resource-Efficient Europe initiative (European Commission 2011a). The aim of both documents is to make far-reaching changes to the way in which Europe produces and consumes energy, while building on what has already been achieved in the area of energy policy. Also, the European Commission recognizes the importance of the energy cooperation in the Mediterranean region and suggests improvements to the regulatory framework and stresses that an integrated regional market in the Maghreb would facilitate large-scale investments in the region and enable Europe to import renewable electricity.

According to the European Commission (2011b), the EU needs to act immediately to get on track to achieve its targets, and a two-step approach was proposed for energy efficiency target setting. In the first step, Member States should set their own national efficiency targets, and in the second step, if the review of the set targets and programs shows that EU is not on track to reach 20 % target, the European Commission will propose legally binding national targets. This is formally laid down in the Energy Efficiency Directive from 2012 (Directive 2012/27/EU). Unfortunately, forecasted energy savings may be rather optimistic if the measures (according to the first and second NEEAPs) will not be implemented successfully and in that case, the expected gap by 2020 will be even larger.

Unfortunately, there are many causes for the projected gap in the residential sector by 2020, and the most of them are associated with symptomatic unbalance between efforts for preparing polices and preparations for policy implementation. A major policy barrier is the absence of the implementation program follow-up and the clear definition of responsibilities of the management bodies on the state, regional, and local level. Almost all Mediterranean countries have defined long-term objectives in their energy strategies, but lack of clear definition of responsibilities with deadlines for the implementation was the crucial reason why many goals have not been achieved. As long as there is no clear definition of responsibilities of the management on the state, regional, and local level and consequences in the case of not fulfilling its obligations, there is no basis for involvement of other stakeholders. This reveals another key barrier for the successful implementation of the energy efficiency programs: *lack of implementation capacity!* Current situation is characterized by the fact that more people are working on planning of the energy efficiency measures than on its actual implementation. With the aim to make any energy efficiency action plan or strategy alive in the real terms, comprehensive and adaptive implementation and follow-up mechanisms have to be developed. The vast majority of policymakers are focused on transposition of common EU energy policies and requirements into national strategic and legislative framework, without in-depth evaluation of the energy efficiency developments in their countries. Unfortunately, in many Mediterranean countries, energy efficiency is not perceived as the most proper instrument for the future sustainable growth. Proper energy and growth policy can play an important role in overcoming these transition challenges, especially by providing financial incentives that lead to accelerated energy efficiency technology development and deployment. Having in mind high percentage of LIH in residential sector and scarce financing resources hardly accessible to LIH, each Mediterranean country will have to revise its energy policy and introduce effective and innovative energy saving mechanisms available for LIH. In the majority of cases, the private-public financing sources are not enough for all the LIH end users. Even the scheme of tax incentives for energy efficiency investment is not followed by the most of LIH due to lack of information and awareness of economic and environmental benefits in terms of the energy and money savings. Therefore, energy-efficient end-user behavior can be an important parameter for the success of national energy policy and programs, especially in LIH residential sector. Correctly navigating the interface between policymaking and human behavior is the key for achieving sustainable energy consumption (European Environment Agency 2013).

As demand for electricity from appliances is increasing, one of the effective and innovative measures includes installation of smart metering. Smart metering can provide desired and necessary link between end-user behavior and energy consumption. Introduction of smart metering, besides the benefits for the utilities, suppliers, and distributions, in its essence has the goal to help consumers to understand their energy consumption. Only a consumer who understands its energy consumption is capable to systematically and sustainably decrease it. On the other hand, utilities are already well aware of their total energy balancing, but with the additional amount of consumption information provided by smart metering, they will be able to better understand and anticipate the end-user behavior and explore this knowledge in synergy of utility measures for optimizing its overall energy performance.

Consumption Feedback Influence on Behavior

According to (Darby 2006), improved feedback may help consumer to reduce its energy consumption by up to 20 %. However, to properly understand the consumption feedback influence on behavioral change, it is necessary to define and understand what is the relation between environmentally and energy-relevant behavior. According to Markowitz and Malle (2012), the environmentally relevant behavior refers to any behavior that can be identified as having a significant direct or indirect impact, negative or positive, on the health and stability of natural (eco)systems. Energy-relevant behavior refers to any behavior that can be identified as having a significant direct or indirect impact, negative or positive, on the energy consumption in selected object or energy system. Since there is a direct link between energy consumption and environmental impact of that consumption, it can be concluded that the energy-relevant behavior is the subset of the environmentally relevant behavior.

Integrative influence model of environmentally relevant behavior (influence model) has been introduced by Matthies (2005) (see Fig. 2). These kinds of models are necessary to understand what consumers do and why they do so. Also, a model proposed by Matthies (2005) can be used for explaining why and how feedback on electricity consumption can reduce consumption (Fischer 2008).

According to (Fischer 2008), the influence model distinguishes between two types of environmentally relevant behavior. The first is habitual behavior or routine, called *environmentally detrimental habits*. The second and above the habits are *conscious decisions*. Habitual behavior or routine is the behavior performed regularly in the same way, and it is not reflected upon. Day-to-day household activities can be classified as such, and many of them are related to household's environmental footprint, mostly through energy consumption activities

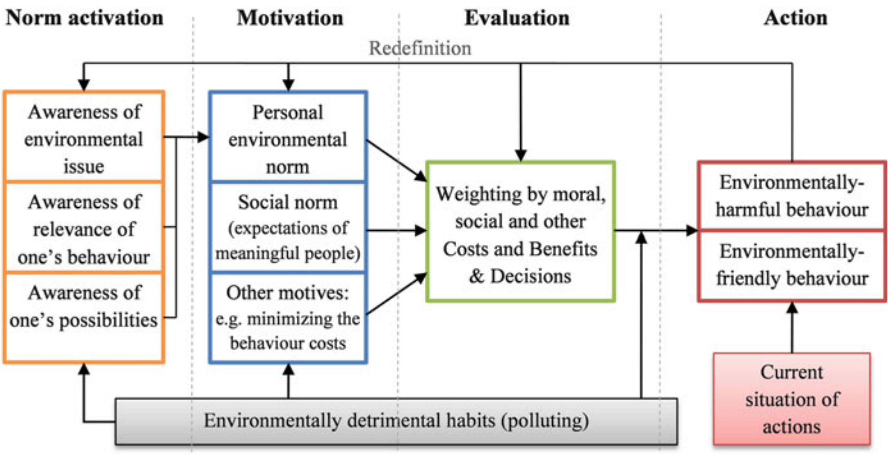

Fig. 2 Integrative influence model of environmentally relevant behavior

(such as cooking, washing, turning on the lights, etc.). Once the routine is established, it may spiral into suboptimal way of doing things because majority of people never really think about an optimum way of doing it anymore. In the field of environmentally relevant behavior, many habits are environmentally detrimental because the environment or energy was not a relevant issue to consider at the time the habit was formed, or because beliefs about environmental effects held at that time have been shown to be wrong, or because the situation has changed so that a once beneficial behavior is not useful anymore (Fischer 2008).

On the other hand, a conscious decision needs to be taken for new norms and considerations to enter the established behavior patterns and break the habits. To do this, a person has to be aware of various options to choose from and to establish proper norms and criteria to evaluate his/her own decisions. The influence model describes this process as *norm activation* and includes three stages of awareness:

- Awareness of an environmental issue which is not solved or tackled by established habits
- Awareness of relevance of one's behavior to the environmental issue
- Awareness of one's possibilities to influence personal behavior to have sense of control.

This process can be illustrated by correlating electricity consumption and electricity bill. One can improperly attribute the high electricity bill to electricity prices and not to one's consumption behavior; therefore, no decision on behavior change will be made. If consumption costs are correctly linked to one's behavior, a person has to realize how to control it. This can only be achieved if a person has sufficient information (i.e., consumption feedback on appliance-specific consumption).

After successful norm activation, a person faces different motives (*motivation*) in order to reach a decision on how to act. Firstly, one is confronted with his/her personal norms and evaluates his/her personal ideas of how to act. Secondly, one is confronted with social norms and what one may consider as socially appropriate or desired behavior. People may sometimes make decisions based on the beliefs and values they perceive to be prevalent in their culture instead of their personal beliefs and values (Chiu et al. 2010). Lastly, there are also other motives not specifically defined in the influence model. In the case of energy consumption in households, these motives may comprise the need or desire for the services associated with electricity consumption on one side and a desire for comfort on the other. When norms and motives conflict with each other, a person has to go through *evaluation or decision-making process*, where moral, social, and other costs and benefits are weighed. During the decision-making process, the persons' norms and motives may be influenced and redefined by available information. According to the model, the final stage is a decision for an environmentally friendly *action*. Under specific conditions, such an action may be performed regularly and develop into a new habit or routine (Fischer 2008).

Four processes described in this model (*norm activation*, *motivation*, *evaluation*, and *action*) can be used for detecting the ways on how consumption feedback can be used to stimulate the conscious decision and development of new energy-efficient habits. In general, consumption feedback gives clear and comprehensive information about energy consumption and can direct consumers' attention toward energy consumption of everyday household activities. Concerning the energy consumption, feedback may focus on two consumption-related problems, problem of consumption costs and problem of pollution (environmental or sustainability issue). With the help of consumption feedback, these issues can influence reasoning process and motivate the consumer for cost savings or for minimizing environmental footprint. Past studies have shown that combining real-time consumption feedback with competition can additionally motivate consumers to reduce their energy consumption and stimulate behavioral change (Petersen et al. 2005). According to Fischer (2008), consumption feedback is most effective if it:

- Successfully captures the consumers' attention
- Draws a close link between specific actions and their effects
- Activates various motives that may appeal to different consumer groups, such as cost savings, resource conservation, emissions reduction, competition, and others.

Smart Metering in LIH

In the light of EU energy saving efforts, the ELIH-Med pilot projects try to identify the most effective smart metering functionalities and services to increase energy efficiency in LIH and achieve measurable energy savings. Within the ELIH-Med project, analysis of twelve multi-energy smart metering projects in the Mediterranean area was performed. Performed analysis confirms that electricity has the leading role in the smart metering projects. Also, electricity smart grids are foreseen to be the backbone of the future energy grids, and smart electricity meters are expected to have the *data concentrator* role for other sources (heat, cold, natural gas, and water). EU Member States are obliged to roll out smart electricity meters for at least 80 % of their end consumers by 2020 and to achieve full coverage by 2022 (European Commission 2011b). In spite of this, smart grid concept cannot be taken for granted as the universal solution for all problems. It is a powerful framework which can assure that the full potential of concrete energy efficiency measure is systematically utilized and verified.

Evaluated smart metering projects were sorted according to nine topics representing different benefits of smart metering for the end consumers on one side and suppliers and utilities on the other, as shown in Table 1. Evaluation confirms that the majority of benefits are at the supply side, indicating the need to put bigger emphasis on exploring consumer benefits in upcoming smart electricity meter rollout.

Unfortunately, in the current situation of economic crisis and cheap electricity available on the market, there is little interest in demand side management, and each Member State is facing the problem of funding the smart metering implementation. Rollout of smart electricity meters should be set in the development plans of

Table 1 Benefits allocation of evaluated smart metering projects

	Topic	No. of projects	Final beneficiary
1	Customer feedback / change of behavior	8	
2	Advanced tariff systems	3	Consumer
3	Other / new customer services (energy service companies)	4	
4	Demand response / demand side management	5	
5	Utilization of reusable energy sources	6	
6	Standardization	1	
7	Interoperability	7	Suppliers utilities
8	Equipment testing	11	
9	System services (distribution, supplier)	8	

individual distribution network operator(s) in each Member State. It is assumed that the necessary funds for implementation would be allocated from the grid fee and distribution network operator(s) would be the equipment owners. In many states, the current practice is that costs of implementing additional services and additional smart metering equipment (i.e., in-home display or individual appliance consumption metering) are charged separately and directly to the consumer. Such practice limits the availability of these services. In the case of LIH, it is crucial that electricity suppliers offer innovative ways of funding for additional services and the equipment. Due to the specific structure of this customer group, one of the options is to stimulate the implementation of additional energy services for energy efficiency by awarding the achieved energy savings in LIH and all in the framework of energy efficiency obligation scheme (Directive 2012/27/EU) where the energy suppliers are obliged to report about achieved energy savings at the end consumers. In this way, suppliers will be more interested in the preparation of suitable energy efficiency programs for the LIH.

Smart Metering and Energy Efficiency Benefits

The use of electrical appliances within households varies significantly in time. The most common measurement interval for load profile analysis in today's electricity grids is 15-min interval. This resolution is satisfactory to show variations in electricity consumption, and it is used for billing purposes. Considering the climate change mitigation activities, smart metering represents technology with the potential for encouraging sustainable change toward the energy-efficient behavior. Smart metering introduces real-time automated meter reading, enables two-way communication, and is suitable for dynamic pricing. Also, the availability of accurate and almost online data for the evaluation of energy consumption has the potential to transform demand forecasting and detection of consumption patterns from a passive historical data-based activity to an active real-time data-driven process. However, smart metering without consumer participation and additional services will, by itself, do nothing to change behavioral pattern and save energy since the meter is simply an *enabler*. Energy savings will be achieved only if the installation of meters is connected with the comprehensive informational campaign which will help consumers to actually understand their energy consumption and stimulate them to move toward sustainable behavioral changes (European Smart Metering Alliance 2010). Also, traditional approaches that focus just on instrumentation and tend to ignore social characteristic of the target group are not suitable for the LIH. In order for energy savings to be realized, problem-oriented approach and customized financial incentives have to be introduced to make energy saving measures more attractive to LIH in economic terms (European Smart Metering Alliance 2010). According to the analysis performed within the ELIH-Med project, these incentives are usually in the form of demand response services and dynamic pricing, introduced by energy utilities.

Demand Response

The target of demand response is to enable active participation of consumers in the market through the provision of consumption flexibility services to different players in the power system. Particularly challenging is the integration of households in the demand response programs due to almost stochastic nature of domestic electricity consumption and available load flexibilities. Therefore, the typical demand response of household consumers is a voluntary reaction to a price signal (Joint Research Centre 2011). Typical response is load shifting where electricity demand is delayed. Although the deployment of smart meters can enable active participation of consumers in the market (i.e., purchase of home energy sources), it is the energy savings and cost reduction which are of interest to LIH consumers and can potentially range up to 15 % (Joint Research Centre 2011). Understanding the relationship between consumption feedback measures, demand response measures, and energy efficiency programs is important to avoid potential conflicts and ultimately failure to capture the full energy saving potential available (European Environment Agency 2013).

Dynamic Pricing

Dynamic pricing encourages consumers to shift consumption away from the peak consumption periods to lower consumption periods, lowering distribution and supply costs. This is achieved through dynamic pricing mechanisms which reflect the cost of supplying electricity. Dynamic pricing is suitable for LIH as it reflects immediately in the lower consumption costs. This mechanism can also utilize the characteristics of Mediterranean environment with high potential for solar electricity generation within certain time of day. In practice, there are several methods and degrees of dynamic pricing, but due to its simplicity Time-Of-Use (TOU), pricing scheme was recognized as the most appropriate for the LIH consumers. TOU tariffs stimulate people to switch their electricity consumption from peak to off-peak hours. The peak hours are known in advance and properly communicated to consumers. The prices may also vary according to the season. Potential for consumer financial savings using TOU tariffs is estimated up to 5 % (Stromback et al. 2011). Dynamic pricing enables energy savings only on the supply side by comprising intelligent integration of centralized and distributed energy generation resources and lowering transmission and distribution losses during peak hours.

Tariff Use Planning and Home Automation

Advanced tariffs are pointless if consumers do not have a proper understanding of its time frames, possible money savings, and environmental benefits due to energy savings on the supply side. For this reason, the consumption feedback introduced in ELIH-Med project (through informative billing and interactive web page) includes additional explanation of implemented tariff systems and proposed the use of home appliances with high intensity of consumption (space heating and cooling systems, electrical boilers for domestic hot water preparation, appliances with adjustable time of operation) according to the implemented tariff system. The home automation in LIH concentrates on installation of electronic plug timers for demand shifting of energy-intensive appliances according to optimal tariffs and programming appliances with integrated time controllers for use in low or off-peak tariff. Proposed concept follows the rules of the simple home automation since the advanced home automation with remote load controllers is out of scope for LIH.

Consumption Feedback Services

The role of consumption feedback is to make the consumption of energy/electricity visible. Feedback can also provide a more direct, detailed, comparable, and comprehensive information about households' energy consumption pattern. Indirect or direct consumption feedback can be provided to consumers utilizing smart metering and its services.

Indirect Feedback

According to (Darby 2006), the indirect feedback is more suitable for demonstrating longer term effects on the energy consumption as the consequence of behavioral changes and applied energy efficiency measures. Through indirect feedback, the consumer has no direct access to the real-time consumption data and is therefore responding to previous consumption behavior and has to rely on processed information. Examples of indirect feedback appropriate for use in LIH are through informative billing and interactive web page. These types of feedback are based on smart meter readings with a combination of appropriate and tailor-made energy efficiency indicators, disaggregated consumption data, detailed energy reports, and other forms of presenting the energy consumption patterns.

Informative Billing and Interactive Web Page

As indicated by *Saving Energy in Social Housing with ICT* project (eSESH deliverable 2010), from the consumers' point of view, one of the biggest advantages of the smart metering implementation is accurate and informative billing. Informative billing includes explanations of the energy saving options regarding the received monthly bill, and it is the favorable feedback option for tenants in social housings (eSESH deliverable 2010). Even though that informative billing provides real and accurate energy consumption data to domestic consumer, the biggest challenge is making this data understandable to all consumers including tenants in LIH. From the ELIH-Med perspective, the informative billing should have the following features:

- Monthly billing based on actual consumption
- Interpretation of monthly consumption in kWh and local currency (EUR)
- Graphic representation of monthly consumption (load profile) with appliance-specific consumption breakdown (where utility provides individual appliance metering). Additionally, a graphic representation must include monthly consumption for at least past 3 months or more (up to 12 months)
- Comparative and normative feedback (efficiency indicators) – e.g., graphic representation of billing consumption compared to consumption in comparable past periods, to average consumption in the past year, correlated to inside and outside temperature difference, etc.
- Common bill for all on-site utility meters (electricity, natural gas, heat, cold, and water).

Interactive web page with the secured personal access can also be utilized as indirect consumption feedback service in LIH. Similar to online banking, energy utilities should provide an option of e-billing (same characteristics as for the classical informative billing) and some degree of energy management (e.g., planning the use of home appliances with high intensity of consumption according to implemented tariff system). As indicated by eSESH project (2010), web services can reach a wider group of tenants also in social housings, and according to eSESH project survey, 85 % of tenants own a PC, and 77 % have access to the Internet.

Direct Feedback

The main characteristic of the direct feedback is that consumers have an immediate and easily accessible display either directly on the smart meter or associated to the smart meter. The primary role of the smart meter is to provide a clear, concise, and understandable information or point of reference for improved feedback, preferably in combination with a separate in-house display (IHD) and individual appliance consumption metering. Using only smart meters, display for direct consumption feedback has its advantages in LIH as it does not bring additional costs for separate IHD.

According to the ELIH-Med project, the direct feedback provided to LIH should include:

- Appropriate indication that allows consumers to easily distinguish between high and low levels of electricity consumption (intensity of consumption)
- Appropriate indication that allows consumers to easily distinguish between peak and off-peak times (indication and price of active tariff) and clear overview of billing consumption (in kWh and currency), broken down by tariff.

Besides meter's display and potential use of IHD, direct feedback allows alarm notification of tenants in the events when abnormal or extensive electricity consumption occurs. Such *alarms* may prove to be the most influential on behavior changes. Due to already available communication channels (SMS or smartphone applications, e-mail), this way of communication is very simple to implement in LIH. According to ELIH-Med, possible triggering events are:

- Tariff switch.
- Steep deviation from average hourly consumption.
- Monthly threshold (average monthly consumption) has been reached.

Pilot Households

Selection of ELIH-Med pilot households, participating in ELIH-Med smart metering experimentation, was based on the household matrix according to which each participating household was categorized.

Required data was gathered with the comprehensive survey which was also used to establish the baseline energy consumption for each observed household/tenants and energy-related behavior. One of the purposes for thorough household categorization was to enable long-term comparisons with an average normalized or benchmarked consumer in the same user category. The need for this comparison is specified in the new Energy Efficiency Directive (Directive 2012/27/EU).

Economic characteristics define the dwellings in LIH category where *low income* refers to households who usually do not have sufficient resources to have an easy access to credit or capital in order to invest in energy efficiency. Social characteristics define the target groups by social and behavior aspects. They are further divided into three subgroups:

- Dwellings size and typology
- Social structure of tenants in household
- Usage of social media.

Table 2 Groups of representative cases

Category	Included cases
Mediterranean space	Cyprus and Malta; Mediterranean region of France, Greece, and Spain
Tenants income	Retired
	Employed
	Unemployed
	Scholarship
Household	Family with children
	Family without children
	Single occupant
	Students
Dwelling typology	Single house
	Semidetached house
	Apartment in multiple dwelling building
	Student dorm
Ownership	Private property
	Rent
	Social housing

Technical characteristics define the technical features of LIH. They are further divided into five subgroups:

- Type of appliances used and their typical usage
- Use of home automation
- Use of lightning
- Heating, cooling, and domestic hot water (DHW)
- Historical data on energy consumption (past energy consumption).

During the pilot households' selection, a special care has been taken to include all envisioned use cases, as defined in groups of representative cases (Table 2).

Surveys of pilot households have highlighted some of the LIH and Mediterranean characteristics which were considered during the use cases development.

LIH characteristics:

- Moderate electricity consumption (reaching national average or below average).
- Energy costs present significant part of household income.
- Use of old and inefficient household appliances.
- Use of passive ventilation is more common than use of advanced cooling or air-conditioning systems.
- Frequently suboptimal living conditions due to inadequate maintenance of living quarters.

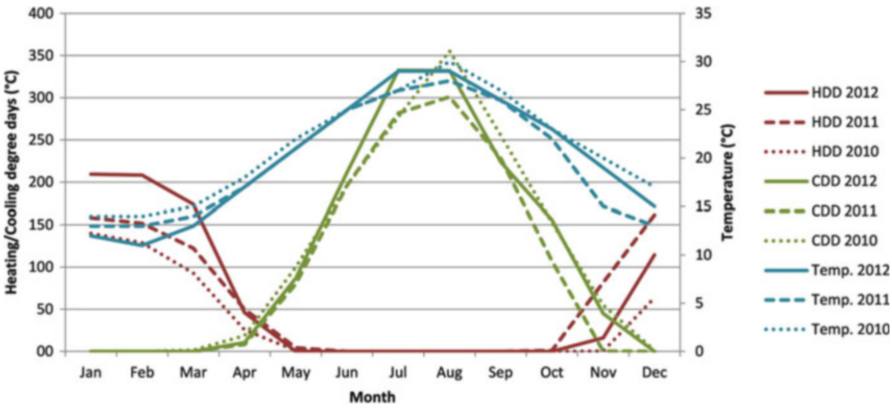

Fig. 3 Cooling and heating degree days for Larnaca, Cyprus

Mediterranean:

- Higher demand for cooling
  Cooling degree days (CDD) exceed heating degree days (HDD) as show in Fig. 3 *for one of the pilot locations (Larnaca, Cyprus) in years 2010 through 2012*
- Low penetration of efficient heating systems (i.e., central heating)
- Low penetration of natural gas grids and district heating
- Electricity as main energy source for cooking

It was noticed that even in cases where natural gas is used for DHW, electricity is usually used for cooking. Also, there is a noticeable rise of electricity consumption during summer months (direct consequence of higher cooling than heading demand) as shown in the case of pilot dwellings in Larnaca, Cyprus (Fig. 4).

Implementation of Consumption Feedback Services

Different types and forms of consumption feedback can be used to influence the reasoning process as described in integrative influence model of environmentally relevant behavior. Three types of consumption feedback presentation were used in selected pilots to target the desired action of the consumer:

- Presentation as environment/pollution problem – equivalent of energy used in CO_2 emissions
- Presentation as family budget problem – costs of energy consumption
- Presentation as consumption problem – consumption in kWh.

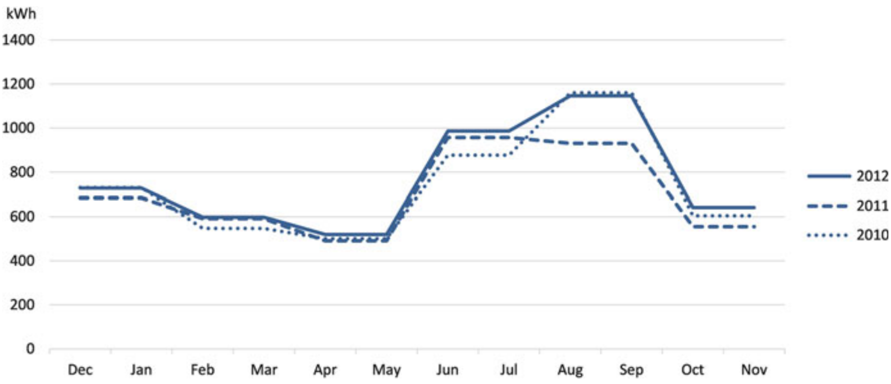

Fig. 4 Sample household electricity consumption

To maximize the consumption feedback impact on the consumer's behavior, ELIH-Med project follows the previously suggested feedback types and include four forms of implementation as shown in Table 3. The first three forms are targeting the behavior of single households, and the last one is targeting the change of behavior on a group of residents. All forms can use several types of presentation. The focus can be either on environment (CO_2 emissions) or energy (consumption in kWh) or on the costs related to consumption. Reduction of costs is particularly important for LIH as even small energy cost savings can have significant impact on the household budget.

Smart Metering Experimentation Plan

Smart metering experimentation plan of the ELIH-Med project was divided into four phases, preinstallation, installation, monitoring, and evaluation (Fig. 5). Phases were designed to follow the integrative influence model of environmentally relevant behavior. Also, the first three phases had an important role in helping LIH consumers to understand how they can use the information provided by smart metering to manage their energy consumption effectively and to save energy.

Preinstallation

Main purpose of preinstallation phase was to assure that selected dwellings comply with LIH criteria and to additionally motivate households participating in experiment (norm activation). Awareness campaign included information concerning all renovation (other ELIH-Med project initiatives) and installation works which were carried out through the experiment. Within the preinstallation phase, the baseline consumption data and past behavioral patterns through survey of participating LIH were obtained. Figure 6 shows the main activities and scope of preinstallation phase.

Table 3 Forms of smart metering implementation

	Form	Type of presentation (in the order of focus)	Target	Number of cases
1.	Appliance-specific consumption breakdown with simple kWh, CO_2, and costs presentation of energy consumption on IHD. Web access with additional consumption breakdown is also available. The pilot projects without web access or in cases where tenants are not customized or willing to use the Internet and monthly reports provided by installed metering equipment are printed by equipment maintainers and distributed to tenants. The form of report is suited to the tenant's needs in each case	Consumption Budget Environment	Behavior of single household	60 households
2.	Sophisticated environmental feedback including consumption and environmental parameters in the form of advanced consumption and environment monitoring system, where energy consumption, temperature, humidity, and other parameters are monitored and presented in individualized web page	Environment Consumption Budget	Behavior of single household	40 households
3.	Utility smart meters are used as main focus point of consumption monitoring, and informative billing is used as main consumption feedback medium. Installation of smart meters is coupled with installation of photovoltaic system as complementary utilizing Mediterranean-specific climate conditions	Budget Consumption Environment	Behavior of single household	60 households
4.	Comparative consumption feedback between several buildings (student dorms) in the form of public dashboards to initiate and stimulate the competition	Environment Consumption	Behavior of a group of residents	5 buildings 144 rooms

Fig. 5 Four phases of interactions in smart metering experimentation

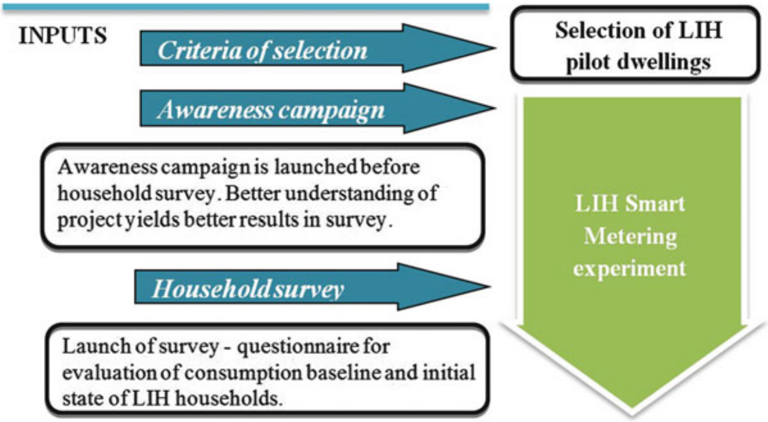

Fig. 6 Preinstallation phase

Experiences from this phase clearly confirm that people welcome the works and changes in their premises when actions are previously well explained. Following a presentation of the project objectives, tenants were in favor of installing smart metering systems into their premises.

The second and equally important finding from this phase was related with the importance of community involvement. The best way of motivating households for installation works and other initial activities is to designate the local representative who coordinates the building activities (organization of education and awareness sessions, coordination of installation process between installers and tenants, etc.). Including the representatives of the local community (neighborhood or building representative) in the preparations and awareness campaigns has proved to be a crucial point in the transfer of sustainable ideas. Initial skepticism, which was particularly present in LIH, has turned into enthusiasm and a desire to cooperate.

Installation of Smart Metering Equipment

During equipment installation phase, it was essential to assure that all LIH participating in the experiment are familiar with installed smart metering equipment. Figure 7 shows the main inputs of the installation phase.

This phase has highlighted the poor condition of LIH living premises. In several cases, due to safety reasons, old wiring needs to be replaced before the installation of new equipment.

Monitoring

Main purpose of this phase was to monitor the effects of implemented consumption feedback services on behavior of the LIH and adjustment of individual smart

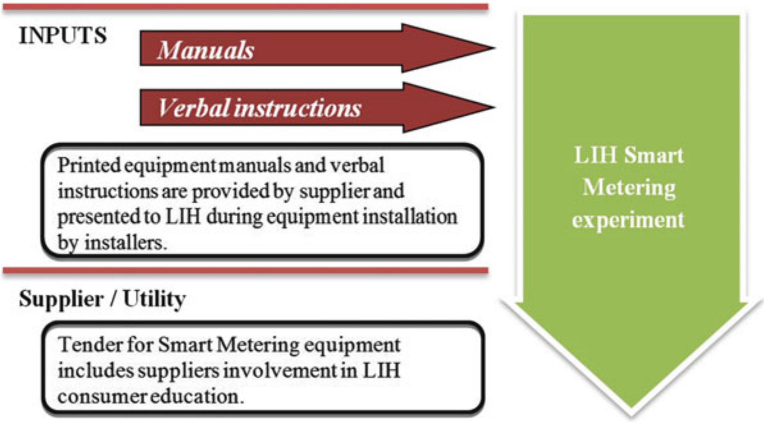

Fig. 7 Smart metering equipment installation phase

metering services according to the survey feedback from households, facilitating the living lab approach to fine-tune different smart metering services to different households (impact of social, cultural, and regional differences). Survey feedback from the tenants on their experience regarding available services was collected and evaluated. Based on these results, the additional adjustment of consumption feedback was done during the monitoring phase:

- Adjustment of monthly report with consumption indicators (printed report or interactive web page).
- In the cases of individual appliance monitoring, it was enabled that the monitored appliances might be changed.

During this phase, three main findings of recognizable benefits have been recorded:

- Tenants have become aware of individual appliance consumption and expressed the surprise of their effects on the monthly electricity bill. In some cases, tenants turn down the heating/cooling when prompted on excess consumption.
- Awareness of current consumption and households' environmental footprint has initiated clear interest about additional energy efficiency measures to be implemented in the households.
- Multiplying the effect of complementary energy efficiency measures. When other energy efficiency measures are implemented (i.e., thermal insulation, double-glazed windows, etc.), the consumption feedback additionally motivates the tenants to adapt behavior to implemented technical updates and modifications.

Figure 8 shows the main characteristics of the monitoring phase.

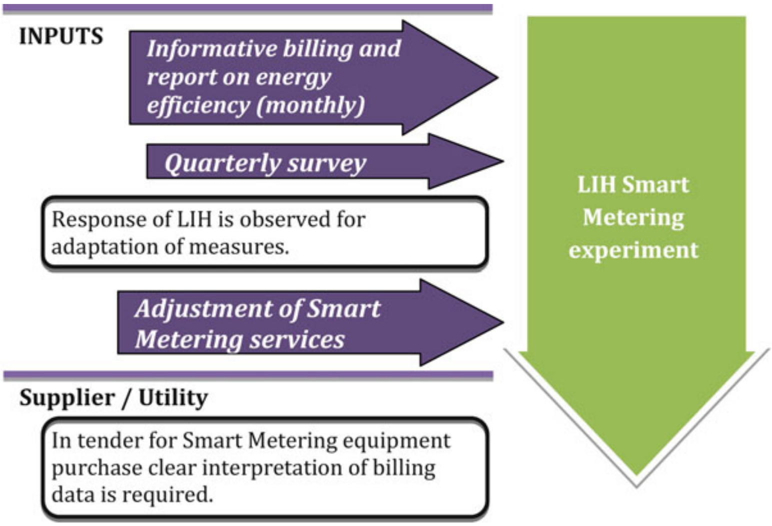

Fig. 8 Monitoring phase

Evaluation

Within this phase, household consumptions as a result of smart metering experiment and induced behavioral changes are to be analyzed. Monitoring and review of the experimentation progress include the consumer experience of the process, new smart metering functionalities, and identified services. Results of the analysis will be used as input in the process of the development of the Energy Savings Verification Model.

The preliminary analysis of LIH electricity consumption within the ELIH-Med project has clearly confirmed electricity saving potential with employment of smart meters and described functionalities. In all cases, principles of demand response and sustainable behavior changes have provided up to 5 % of electricity savings. In the cases where LIH consumers have applied additional load optimization techniques (economical usage of household appliances) stimulated by consumption feedback, up to 7 % savings have been achieved.

Future Research Challenges

Smart metering is primarily intended as an active element of utilities' energy distribution operations in smart grid infrastructure, but it has also shown potential as climate change mitigation tool through two additional *side effects*. The first is a support for the energy efficiency services and measures as an independent and customizable tool providing a more direct, comparable, and comprehensive information about households' energy consumption pattern. Secondly, smart metering infrastructure enables proper energy saving verification and validation. Based on the preliminary results from the ELIH-Med project, electricity utilities have the vital role in the smart metering implementation and must be involved in providing LIH with new customized services. Also, multi-energy metering must be established when other energy utilities are present (water, natural gas, district heating, and cooling), and the advantage of existing electricity grid infrastructure has to be explored. If smart meters are used for all utilities on-site, communication with these meters can be done via a smart electricity meter since the electricity meter can always provide the power supply for the communication. Sharing the remote communication channel can also greatly reduce the combined costs of communication and therefore costs for the consumer, which is vitally important for LIH. Even though that electricity is the most dominant energy carrier in the Mediterranean area, only a complete overview of household energy balance from all utilities (electricity, water, natural gas, district heating, and cooling) can induce proper consumer behavior changes as savings in one energy form may be replaced by increased consumption in the others.

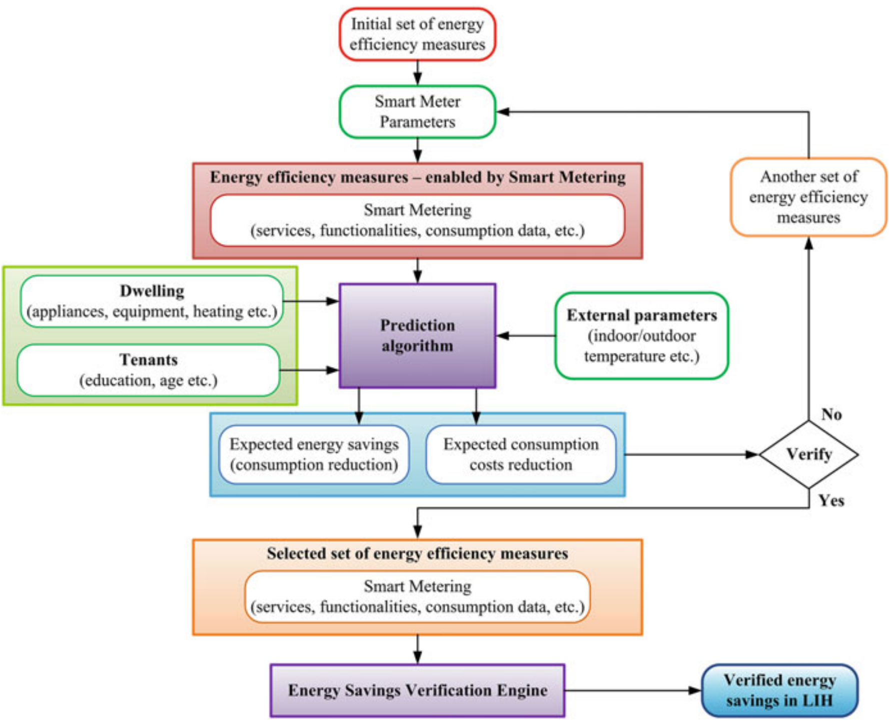

Fig. 9 Energy and cost saving prediction and verification flowchart

Energy Saving Verification

Results of the ELIH-Med smart metering experimentation process will be used to build an algorithm for the verification of energy savings considering different functionalities of smart meters in combination with the behavioral changes, implemented energy efficiency measures, and other influential factors. The experimental results enabled contextualization of the energy consumption where the notion of context refers to (actual) characteristics of the household and its environment, typology, social status, appliances, and devices. Database of performance results will also enable energy performance benchmarking, where a selected and comparable LIH can be benchmarked based on the input data gathered by household survey. Finally, the prediction algorithm based on the results of smart metering experiment will enable the forecast of energy savings and energy consumption cost reductions as shown in Fig. 9.

The outcome of validation model should also help Member States to decide which energy efficiency objectives and which benefits to the end consumers are taken into account when obliging market participants and setting minimum functionalities for smart meters. This obligation is established in the new directive on energy efficiency (Directive 2012/27/EU), which in Article 9(2)(a) states that Member States must ensure that "*objectives of energy efficiency and benefits for final customers are fully taken into account when establishing the minimum functionalities of the meters and the obligations imposed on market participants*."

Conclusion

Successful energy efficiency policy must be adaptive and must rely on the empirical data. Smart metering is a powerful tool for monitoring and verification and must be part of the comprehensive energy efficiency and climate change mitigation policy. Implementation of energy efficiency measures and utilization of the smart metering and its consumption feedback services in LIH may prove to be quite challenging introduction of changes in a very complex environment. However, energy-efficient behavior is a critical parameter for the success of each national energy policy and programs.

The ELIH-Med project clearly confirmed the importance of community involvement before and during the smart metering implementation. Also, in the case of LIH, it has been confirmed that proper and tailor-made consumption feedback has a potential to influence on the established behavioral patterns, break the habits, and initiate environmentally friendly actions. To make such feedback available, energy suppliers should offer innovative ways of covering the costs of additional smart metering services and equipment in LIH. Although individual consumption registration of energy-intensive household appliances may prove to have big influence on consumer behavior, it is the notification about relevant and extraordinary events in energy consumption that proved to have the biggest impact to behavioral changes in LIH. Also, it has been noticed that the awareness about energy consumption and households' environmental footprint has raised the interest for additional energy efficiency measures. In cases where other energy efficiency measures were implemented, the consumption feedback additionally motivated the tenants to adapt their behavior and achieve even bigger savings. Internet access has proved to be available for the majority of LIH and should be used for enriched consumption feedback. As consumption feedback will be specific to LIH, this is also an opportunity for different social programs to act through energy efficiency awareness campaigns in providing additional information and programs utilizing smart metering communication channels.

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Transition to Low-Carbon Future in Nigeria: The Role of Pro-Environmental Behaviors

Oluwatosin E. Ilevbare, Maruf Sanni, Femi M. Ilevbare, and Godwin A. Ali

Contents

Abstract

Various environmental challenges pose a lot of threats to sustainable development, among which are global warming, air pollution, and loss of biodiversity. Many of the causes of these challenges are rooted in unsustainable human behaviors and thus can be managed by changing the relevant behavior so as to reduce its ecological and detrimental impacts. This chapter explores the potential for discouraging behavior that contributes to greenhouse gas emission into the atmosphere. It also suggests alternatives to fossil fuel-dependent pathways,

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giving attention to the behavioral and social drivers of change in Nigeria. The chapter further prescribes behavioral and social changes into the roles played by households, business sector, and government policies. Strategic framework and initiatives for energy saving and adoption of low-carbon pathways in the medium- to long-term were suggested. The chapter concludes that to move toward a low-carbon economy in Nigeria, there is the need to institutionalize appropriate behavioral and social changes in the society as well as developing technological capabilities in the area of clean technologies.

Keywords

Low-carbon future • Nigeria • Greenhouse gas emissions • Climate change • Pro-environmental behaviors

Introduction

Global warming caused by climate change has been regarded by many scholars to be the most severe environmental challenge of the present time. Metz et al. (2007) estimated that the average global temperature has increased by approximately 0.6 °C over the past 150 years and projected to increase between 1.4 °C and 5.8 °C by 2100 if greenhouse gas emissions are not significantly reduced. Many developed and developing countries are faced with the dilemma of reducing the emissions of greenhouse gases into the atmosphere or face the considerable risks associated with global warming such as drought, excessive flood, sea level rise, food insecurity, increasing number of extreme events, etc. A lot of evidences in the literature support the fact that human activities are contributing immensely to global warming and that our failure to act now could lead to disasters such as increase mortality, disease, injury, heat waves, storms, and floods (Anderegg et al. 2009). Consequences of extreme climatic changes as a result of global warming are severe, and there has been considerable and disturbing concern among various environmental scientists and policy makers in various countries of the world. According to the World Health Organization (2002), it was estimated that global warming is responsible for 154,000 deaths worldwide by creating conditions more favorable for the spread of diseases such as malaria, dengue fever, and diarrhea.

Although the total greenhouse gas (GHG) emissions in Nigeria is minimal compared with the global average, nonetheless the carbon footprint in the country is on the increase due to her large population and fossil fuel-dependent economy. The major contributors of CO_2 in Nigeria include land use, land use change and forestry (LULUCF), energy consumptions, industry, solvents use, agriculture, and waste management (see Fig. 1). In 1994, the gross carbon emission was 52.5 Tg–CO_2–C, while the net uptake, principally from land use change, was 10.4 Tg–CO_2–C. This gives a net carbon emission of 42.1 Tg CO_2–C (FME 2003). The summary of national emissions of GHG is 192 Tg CO_2, 17.0 Tg CO, 5.9 Tg CH_4, and 2.2 Tg NMVOC. Others include 660 Gg of NO_X and 12 Gg of N_2O. Meanwhile, the total GHG emissions (in CO_2 equivalent) for the three main

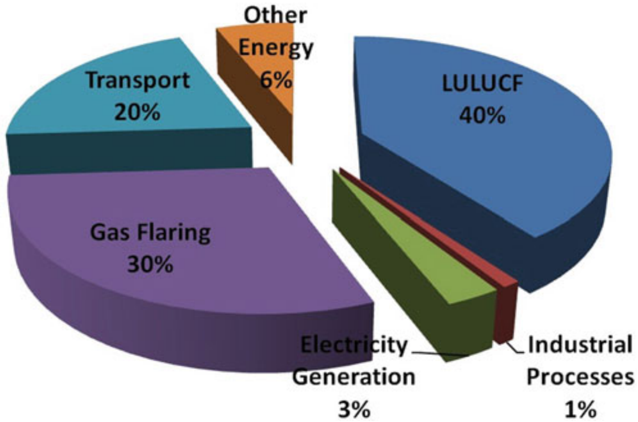

Fig. 1 Major sources of CO_2 emissions in 1994

greenhouse gases (CO_2, CH_4, andN_2O) and from the five main sectors (energy, industry, agriculture, land use change and forestry (LUCF), and waste) were about 330,946 Gg CO_2e in 2000. The net CO_2 was 214,523 Gg, representing 65 % of the national GHG emissions, methane (CH_4) was109,319 Gg CO_2e or 33 %, and nitrous oxide (N_2O) totaled 7,104 Gg (CO_2e) or 2 % (FME 2010).

Climate Change Impacts in Nigeria

Over the years, the conditions of human and capital developments remain challenging. Out of 187 countries ranked on the United Nations Development Programme (UNDP) Human Development Report (2013), Nigeria's position is 153. Average life expectancy is 52.3 years compared with 64.6 years in Ghana. Today, the maternal mortality ratio (deaths per 100,000 live births) is 630. The country's Multidimensional Poverty Index (MPI) value (the share of the population that is multidimensionally poor adjusted by the intensity of the deprivations) is 0.31, while the adult literacy rate stands at around 61.3. Climate change impacts are bound to add to some of these challenges. Climate change occurs when there is a change in the steady state of equilibrium in the climate system causing changes in one or more of the components making up the system (Metz et al. 2001; Kak'mena et al. 2012). Climate change is anticipated to impact across ecosystem, societies, human livelihoods, food security, human health, and well-being. This could be changes in temperature, changes in seasonal occurrences of rainfall, etc. According to the Intergovernmental Panel on Climate Change (Metz et al. 2001), a rise in temperature of between 1.4 °C and 5.8 °C by 2100 will have serious negative effects on the socioeconomic well-being of the people. Some of these effects in Nigeria include the following, among others: increase in amount of rains and number of rainy days, flooding in the coastal areas, and higher risk of 100-year flood occurring at shorter intervals. Africa is believed to be one of the most vulnerable continents to the effects of climate change (Obasi 2000; Metz et al. 2007). Nigeria, like other African nations which are at the receiving end of the effect of global climate change, is counting its losses from the impact of the phenomenon. From desertification and drought in the north to gully erosion and flooding in the south, the Nigerian citizens are directly feeling the effect of climate change on their socioeconomic life. There are many indications in the literature that the climate has not just changed, it has affected the way people conduct *business* in Nigeria. For instance, there has been increasing incidence of health risk (Eke and Onafalujo 2013), reduction in agricultural productivity (Dinar et al. 2006; Ayinde et al. 2010), reduced access to quality education, reduction in rainfall in already desert-prone areas of northern Nigeria (Medugu 2011), and increase in conflict occurrence and insecurity. All these have serious effects on the standard of living of the Nigerian populace and hence on their quality of life.

Over the past few decades, Nigeria like many other parts of the world is not immune to the adverse effects of climate change. For instance, studies have predicted that there is a possible sea level rise from1990 levels to 0.3 m by 2020 and 1 m by 2050 and rise in temperature of up to 3.2 °C by 2050 under a high climate change scenario (IFAD 2001). Under a low climate change scenario, however, there is possibility for a sea level rise of 0.1 m and 0.2 m by 2020 and 2050, respectively, and a temperature increase of 0.4–1 °C over the same period (IFAD 2001). The study also stated that a sea level rise of 1 m could result in loss of 75 % of the Niger Delta.

The negative impacts of climate change such as temperature rise, ill-health, erratic rainfall, sand storms, desertification, low agricultural yield, drying up of water bodies, and excessive floods are already being experienced most especially in the semiarid parts of Nigeria (Medugu 2011). Environmental degradation and attendant desertification are major threats to the livelihoods of the inhabitants of these dryland states of Nigeria. Also the increasing population pressure has led to intensive agricultural land use, overgrazing, bush burning, and high rate of extraction of fuel wood.

Nigeria's strategy has been to reduce greenhouse gas emissions while promoting sustainable economic development. Some of the ways proposed to achieve this include the passing into law the climate change policy and use of clean natural gas for productive uses in the power sector and in homes for cooking and in transport as compressed natural gas (CNG), among others. Few attempts have however been made by the government to explore behavioral approach to environmental sustainability in Nigeria.

Environmental Sustainability and Low-Carbon Development in Nigeria

Environment has been defined as the totality of the places and surroundings in which we live, work, and interact with other people in our cultural, religious, political, and socioeconomic activities for self-fulfillment and advancement of our communities, societies, or nations (Akinbode et al. 2003). Sustainability is a development that meets the need of the present without compromising the ability of the future generations to meet their needs (WCED 1987). Sustainable development stands on three pillars: social, economic, and environmental development. Sustainability in the area of environmental development is a policy by which the environment can be protected from pollution and dilapidation and replaced or restituted after degradation. In other words, environmental sustainability involves making decisions and taking action that can contribute to low-carbon economy in the interests of protecting the natural environment, with emphasis on preserving the capability of the environment to regenerate and ensure good quality of life.

Public perceptions and attitudes are critically important to both the supply and the demand side of the transition to a low-carbon economy (Poortinga et al. 2004). The reluctance of the public to accept new energy development in their community has been highlighted by the UK government as one of the main challenges to the transition to a low-carbon economy. On the demand side, perceptions of the need to take mitigating action against climate change, and of the ability to act on this, can be key precursors to personal behavior change and compliance with wider policies aimed at modifying behavior (Spence and Pidgeon 2009).

As Nigeria firms up strategies to promote environmental sustainability and improve quality of livelihood of the populace, there is the need to promote a low-carbon society through changing or modifying what people buy and how they work and travel. A low-carbon society has been described as the one that uses less energy and fewer resources through greater energy efficiency, which can also mean reduced costs for households and businesses (Scottish Government 2010). Such society consciously incorporates renewable sources such as wind, water, wave, and solar power in the energy mix. In all, a society such as this will be able to realize the economic opportunities that come from developing clean technologies, creating low-carbon manufacturing industries, and building more sustainable infrastructures and creating thousands of green jobs. In essence, people will be able to live healthier and more sustainable lifestyles. There are clear benefits in moving toward a low-carbon society. For instance, in the analysis of options for low-carbon development in the oil and gas sector of Nigeria, the low-carbon scenario reduced emissions by 750 $MtCO_2e$ (million metric tonnes of carbon dioxide equivalent emissions) or 34 % of the reference emissions. The revenues from sale of the additional gas and associated liquid petroleum gas (LPG) generated a positive net present value (NPV) of $7.5 billion at a 10 % real discount rate. It was concluded that the low-carbon scenario not only significantly reduces emissions but also generates higher economic returns from Nigeria's gas resources (Raffaello et al. 2013). However, there are challenges in trying to transition to low-carbon economy. For example, the capital cost of implementing the emission reduction options included in the low-carbon scenario is estimated at US$17 billion (Raffaello et al. 2013), but it is generally believed that the benefits of low-carbon economy generally outweigh the challenges in the long run.

Understanding how to change people's behavior toward more pro-environmental actions is thus a critical part of these processes. This study examines the evidence currently available on changing attitudes to sustainability and offers views on a number of different ways in which behavioral change could be encouraged among the key stakeholders in the country. In order to be able to achieve this, these critical questions are raised: Why do we consume in the ways that we do? What factors shape and constrain our choices and actions? Why (and when) do people behave in pro-environmental ways? And how can we encourage, motivate, and facilitate more sustainable attitudes, behaviors, and lifestyles?

Climate Change Response in Nigeria

Responding to climate change from both mitigation and adaptation perspectives involves strategic approaches from policy, regulatory, and institutional frameworks as well as technological point of views (FMENV 2010). It requires that all sectors of the economy be comprehensively addressed because of the multifaceted nature of the expected impacts of climate change. Another key aspect of these strategies is that of mobilization of financial resources to implement the programs. All these activities would only be possible with the establishment of a sustainable national climate change policy framework.

However, Nigeria's response to climate change threats in the context of policy development framework remains a major challenge. Despite its high dependence on fossil fuel and high vulnerability to climate change, Nigeria has just passed into law the climate change policy. This policy has a response strategy that could address the issues of mitigation and adaptation measures and financial requirements and mobilization. As a signatory to the Kyoto Protocol, the country has come up with this policy to address the impacts as well as maximize the opportunities there in. The policy focuses on adaptation, mitigation, finance, and technology. Presently, there are a number of existing policies that could be adapted and implemented in anticipation of climate change to reduce its potential adverse effects (FMENV 2010). Some of them include the first national communication to the United Nations Framework for Climate Change (UNFCCC), National Adaptation Strategy and Plan of Action on Climate Change for Nigeria, Greenhouse Gases Mitigation Options Assessments for Nigeria (2000–2040), National Energy Policy, Renewable Energy Master Plan, Natural Gas Flare Out Policy, etc.

National Policy Efforts to Combat Climate Change in Nigeria

The Federal Ministry of Environment (FMENV) is in charge of addressing issues related to climate change in Nigeria. The ministry has mandates to address the challenges of key environmental issues such as that of land degradation (deforestation, desertification, and coastal and marine environment erosion), air and water pollution, urban decay and municipal waste, as well as hazards of drought, coastal surges, floods, and erosion. The Nigerian government elaborated a National Environmental Policy in 1989. The policy was revised in 1999 to accommodate new and emerging environmental concerns. The goal of the revised policy is to achieve sustainable development in Nigeria and, in particular, to (i) secure a quality environment adequate for good health and well-being, (ii) promote the sustainable use of natural resources, (iii) restore and maintain the ecosystem and ecological processes and preserve biodiversity, (iv) raise public awareness and promote understanding of linkages between the environment and development, and (v) cooperate with government bodies and other countries and international organizations on environment matters (FMENV 2010).

In order to coordinate activities related to climate change matters, the FMENV created a Special Climate Change Department (SCCU). It was established in recognition of the importance attached to the issue of climate change and global warming and in view of the enormity of activities required for the implementation of the Climate Change Convention and the Kyoto Protocol (FMENV 2010). This unit has since been upgraded to the status of a substantive department in the ministry. The department has been the driver of the ministry's policy and programs on climate change. In addition to responding to international obligations, the Climate Change Department has been coordinating the activities of the Inter-ministerial Committee on Climate Change. It also oversees the activities of the Presidential Implementation Committee on the Clean Development Mechanism (CDM) in Nigeria. The Nigerian government also upgraded the Department of Meteorology in the Ministry of Civil Aviation to a full-fledged Nigerian Meteorological Agency (NIMET) in 2003. This was carried out so as to improve the national capacity to generate observational climate data and climate monitoring systems. The Federal Government has also enacted quite a few number of specific policies and action plans that could be adapted to support national climate change mitigation and adaptation response. Some of these initiatives include (i) National Policy on Drought and Desertification; (ii) Drought Preparedness Plan; (iii) National Policy on Erosion, Flood Control and Coastal Zone Management; (iv) National Forest Policy; and (v) National Biodiversity Strategy and Action Plan.

Other initiatives include the creation of the House Committee on Climate Change. This committee is mandated to promote sustainable behavior across the civil society, private sector, and government. Many states across the country are also taking a proactive stance with regard to climate change issues. For instance, Lagos State created a Climate Change Department and raised awareness through the Lagos State Public Schools Climate Change Club. Lagos State is also the only state in Nigeria that has a functional climate change policy. However, Niger State was the first state to convene a climate change dialogue and has harmonized legislation and restructured institutions to promote sustainable development and respond to climate change issues (FMENV 2010). Nigeria's First National Communication (FNC) was produced in 2003. This communication presented Nigeria's gross national emissions of GHGs by sources and by sinks as well as impacts, vulnerability, and adaptation measures against climate change impacts. The draft report of the Second National Communication (SNC) to the United Framework Convention for Climate Change has been finalized and the country is in the process starting the Third National Communication. The government of Nigeria has finalized a 10-year plan for stimulating Nigeria's economic growth (Vision 20:2020). The plans aim, among others, to reduce the impact of climate change on socioeconomic development processes in the overall context of preserving the environment for socioeconomic development. Other initiatives along this line include National Economic Empowerment and Development Strategy (NEEDS) I and II, 7-Point Agenda, etc. It is envisaged that these economic initiatives will strengthen environmental governance and optimize economic benefits from sustainable environmental management (FMENV 2010).

Many local and international development partners have also intervened with a lot of activities to raise awareness on climate change impacts in Nigeria. For instance, the British High Commission, with ICED and Christian Aid, supported advocacy programs to raise awareness in the National Assembly through the Nigeria Climate Action Network. A working document on adaptation strategies of actions which identifies interventions across 11 different sectors in which adaptation will be crucial for Nigeria has also been developed by the Climate Change Department and the Heinrich Böll Stiftung (HBS) Foundation. The Canadian International Development Agency (CIDA) supported the Building Nigeria's Response to Climate Change (BNRCC) program in a bid to explore the ecological problems and perceived impacts in certain ecological zones in Nigeria. The study covers the assessment of vulnerability, impacts, and adaptation to climate change in two sectors: agricultural production and food security and water resources (marine, freshwater/underground, rain) and water quality change. FAO has also carried out the assessment of potential impacts of climate change on agriculture, food security, and the environment in Nigeria.

Low-Carbon Society and Behavioral Strategies: The Conceptual Framework

A global treaty which encouraged action to reduce/stabilize greenhouse gas emissions was agreed upon in 1992. This treaty led to the establishment of the UNFCCC. The treaty was later strengthened by committing the signatories to agree to take action to cut their greenhouse gas emissions through the Kyoto Protocol. In 2005, the Kyoto Protocol entered into force and later ended in 2012 (UNESCO 2010). At COP 17 in Durban, the EU agreed to a second commitment period for the Kyoto Protocol (KP2), but there was no time to finalize all the rules. In Doha, at COP 18 the rules for that second commitment period were finally agreed upon, allowing it to move forward for another 8-year period (2013–2020). It is however surprising that most of the international agreements failed to incorporate human dimension which is key to the analysis of climate change issues. Rather most of the discussions rationalize human behavior and assume that they can be guided by just the economic tools (Kloeckner and Blobaum 2010). As such, the effects of climate change on humans' experiences and behavior as well as the psychological explanations behind humans' climate-related behaviors have not been adequately reflected in many of these agreements (Kloeckner and Blobaum 2010). As a result of this, many of the approaches to the issue of climate change have fallen short of addressing the average human's pro-environmental behaviors.

Climate change adaptation and mitigation is a multidimensional issue that demands integration across various key elements of the society such as household, business sector, and government. This multi-stakeholder dimension and approach is one of the best ways to successfully guide the process of changing human attitudes, perceptions, and behavior toward climate change impacts. Kloeckner and Blobaum (2010) and UNFCCC (2007) substantiated this fact by reiterating that understanding people's behavior related to climate change (mitigation and adaptation) is crucial for successfully dealing with the future challenges. The conceptual framework in Fig. 2 underscores the need for attitudinal change and energy-efficient behaviors among key stakeholders: household, business sector, and government. It is believed that the highlighted activities under these key stakeholders could contribute substantially to effective low-carbon economy.

Thinking Forward: Reducing Nigeria's Carbon Footprints

There are many interventions that can be used to generate desirable pro-environmental behavior changes. These varieties of strategies can be broadly categorized into two: regulatory and nonregulatory or voluntary (see Fig. 3) measures. Regulatory interventions involve making and changing laws or establishing rules that eliminate or restrict choice. A good example of this type of initiative is the fiscal measures which are financial incentives and disincentives that can encourage behavior change. Other examples of regulatory measures include performance and technology standards. Within the category of nonregulatory or voluntary interventions (Fig. 3), examples include nudges (see Table 1), labeling, negotiated agreements, training, and awareness. A mix of these policies has the capacity to provide better information, enabling emitters (both consumers and producers) to make better decisions to reduce their carbon footprints.

With regard to climate change impacts, it has now become a common knowledge in the private, public, and policy arenas that in order to secure more sustainable future, current patterns of behavior have to be modified. Although modifying behavior can be beneficial to the environment, change often does not occur among individuals on their own accord (Cervigni et al. 2013). It has been discovered that people still choose to act in an environmentally unfriendly manner even when they are aware of the benefits attached to acting differently. The reasons for such behavior fall into a number of categories that include financial cost (Stern 2000), lack of alternatives, anticipated regret, inconvenience (Stern 2000), ignorance, lack of concern, laziness or habits, the common dilemmas (Cervigni et al. 2013), and perceptions that their contribution can make no difference, i.e., powerlessness (Jackson 2005). Klockner and Blobaum (2009) proposed a model named Comprehensive Action Determination Model (CADM). This model conceives behavior to be predicted directly by three different motivational paths: The first is that "what people intend to do has an impact on their behavior," i.e., part of a person's

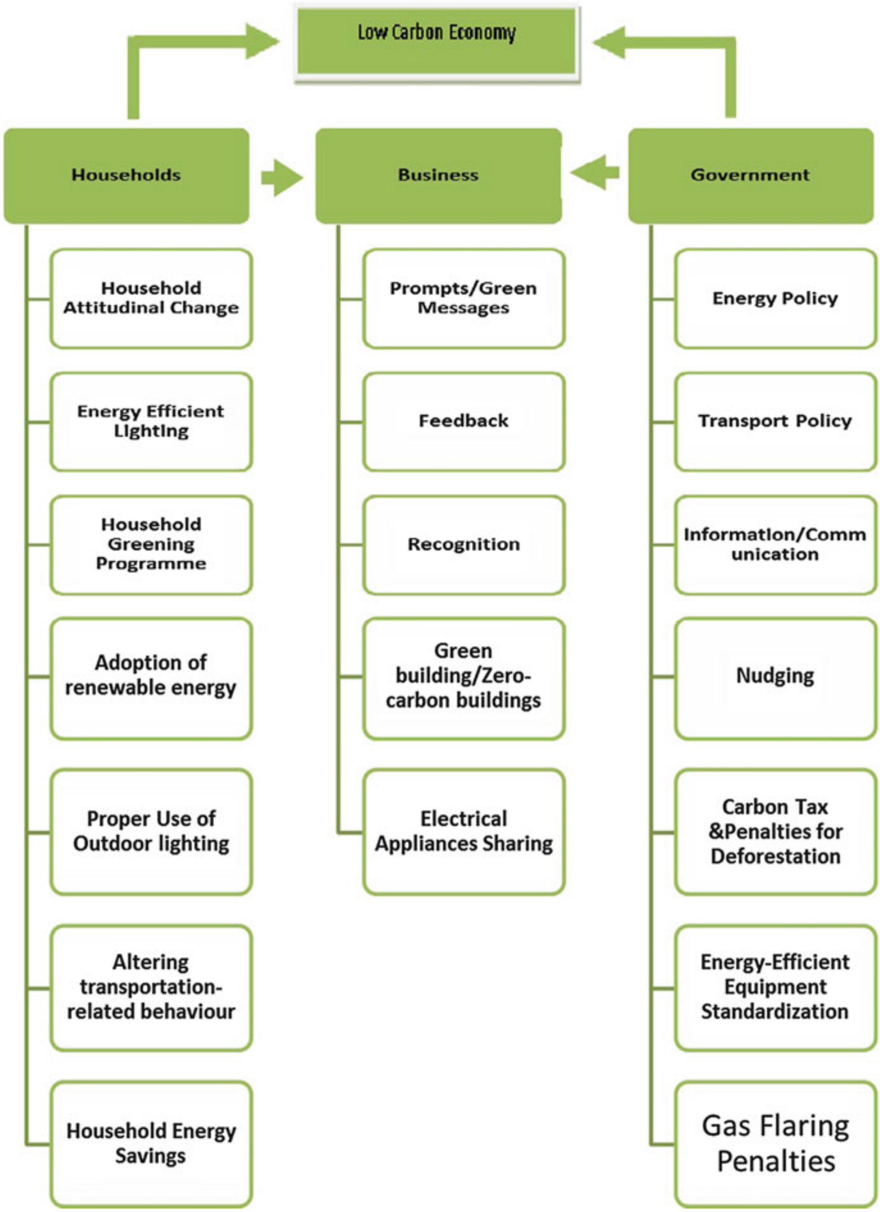

Fig. 2 The conceptual framework of action for the key stakeholders

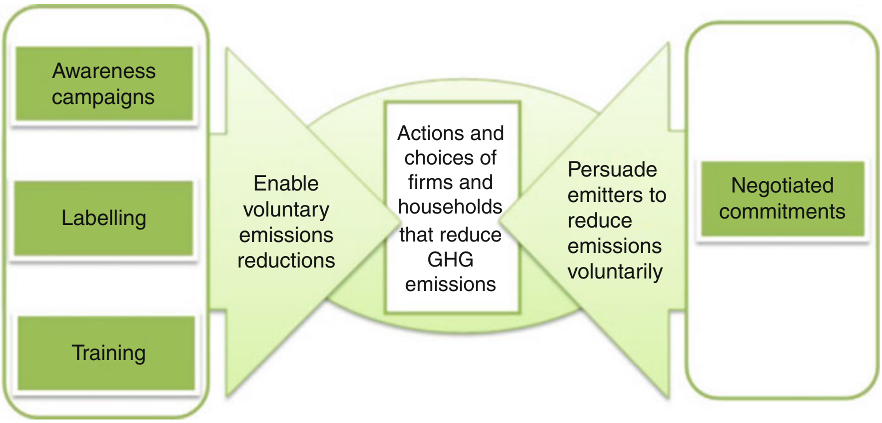

Fig. 3 Voluntary and information-based programs

behavior is assumed to be under the control of intentional decision-making processes. Secondly, “a person’s behaviour is under the control of the objective situational conditions and their subjective perception,” for example, when there is no mode of transportation that prevents carbon emission, an individual will not be able to enact the desired behavior even if they intended to do so. The third motivational path is “If people perform an action repeatedly, they start building routines and habits that over time, take control over their actions.” That is, habitual processes have the power to moderate the relations between intentions and behavior.

These factors have contributed significantly to the understanding of environmental behaviors among consumers such as individual households, governmental and nongovernmental organizations, etc. Meanwhile, studies have shown that one of the best determinants of future behavior is past behavior: people tend to be regimented in carrying out their tasks and stick with the old habits (Ouellette and Wood 1998). As a result of this, to change from undesirable old habits, there is the need for deliberate intention. In view of this, interventions that motivate or nudge (see Table 1) people toward pro-environmental behaviors should be targeted at their behavioral choices. It has been noted that such guided interventions enhance an individual’s capacity to change (Verplanken et al. 1998). Meanwhile, pro-environmental behavior has been described as action that reduces harm to the environment or even benefits it (Steg and Vlek 2009). However, it should also be noted that there are certain barriers to pro-environmental behaviors most especially as it relates to energy use (see Box 1). Examples of pro-environmental behaviors include recycling household wastes, purchasing “sustainable” products, using energy-efficient appliances, choosing green electricity tariffs, composting garden and kitchen waste, conserving water or energy, buying organic food, returning electrical goods for reuse or recycling, switching transport mode to more

Table 1 Types of interventions

		Interventions	Illustrative examples to encourage energy-saving light bulbs
Regulation		Eliminate choice	Prevent the use of conventional, inefficient light bulbs
		Restrict choice	Stop selling conventional light bulbs
Fiscal measures		Guide through financial disincentives	Increase tax on conventional light bulbs
		Guide choice through financial incentives	Reduce tax or subsidize energy-saving light bulbs
Nonregulatory and non-fiscal measures		Guide choice through nonfinancial incentives or coerce through nonfinancial disincentives	Offer a reward, e.g., entry into a prize draw, for buying energy-saving light bulbs
		Persuade individuals using argument and coercion	Persuade people that improving energy efficiency is important and that energy-saving light bulbs help save energy while reducing bills
	Nudges	Guide choices through changing the default policy	Supply energy-saving light bulbs in new light fittings and lamps
		Enable choice by designing or controlling the physical or social environment	Make energy-saving light bulbs the most prominent type at the point of sale
		Use social norms and salience, provide information about what others are doing	Use advertisements to show how many people are buying energy-saving light bulbs
		Provide information to educate and increase knowledge and understanding	Explain how energy-saving light bulbs work and how they save energy
		Do nothing or monitor the current situation	Track sales in different types of light bulb

Source: POSTNOTE (2012)

sustainable ones, buying remanufactured or reused goods, reducing material consumption, etc. (Jackson 2005). Failure of several interventions has been linked to the complexity involved in changing behaviors. For instance, have argued that many interventions to promote sustainable behaviors do not take into consideration the rich mixture of cultural practices, social interactions, and human feelings that influence the behavior of individuals, social groups, and institutions. It is within this context that this chapter examines the roles of households, business sector, and the government in engraining low-carbon future in the country.

Box 1: Barriers to Energy Behavior Change

There are many barriers to energy behavior change to be considered when designing policy:

Low prominence of energy efficiency – energy is "invisible" and saving energy is often a low priority.

Low cost of energy – efficiency measures can be, or are perceived to be, relatively expensive.

Availability of energy-efficient technology.

Lack of knowledge and understanding of energy-saving behavior and efficiency measures available.

Hassle factor of installing efficiency measures, such as the need to clear out the loft before insulation.

Aesthetics, for example, where people are concerned about the attractiveness of energy-saving alterations.

Social norms (what other people are doing around you) – norms influence people's behavior and can prevent them from adopting a new efficiency measure.

Policy acceptability – for example, the government is unlikely to heavily regulate energy use because of a lack of acceptability within the electorate.

Source: POSTNOTE (2012)

Households

Households are vital to delivering pro-environmental change, not just for themselves but also within organizations and networks as "agents of change." Everyday choices can make a difference from household travel, to use of electrical appliances, to cutting down of trees, to shopping choices. Households could engage in behavior geared at restoring and conserving the environment such as the use of energy-efficient lighting, household greening program, adoption of renewable energy, avoidance of forest deforestation, proper use of outdoor lighting, planting of appropriate tree species, use of energy-efficient stove at home, and planting of drought-resistant crops.

Household Attitudinal Change

Perceptions of the need to take mitigating action against climate change and capacity to take action are key determinants to personal behavioral or attitudinal change toward compliance with policies aimed at motivating such behavioral changes. Attitudes are the evaluations and associated beliefs and behavior toward some object or new experience. Attitudinal change most often precedes behavior. Explained that the idea behind attitude-behavior relationship is that the more people know about and understand the connections between their own behavior and a range of environmental threats, the more likely they will adjust their behavior accordingly. In essence, this requires households to logically consider incoming information and apply this new knowledge to their own behavior. Public perception and attitudes play a vital role in the transition to low-carbon emissions. However, it has been argued that attitudes are mainly context dependent and therefore not stable over time; thus they are not really suitable as a stable predictor of behavior. It has been suggested that the causal relation between attitude and behavior can also be bidirectional. For instance, Dwyer et al. (1993) and Leiserowitz et al. (2010a) found that in examining attitudes toward climate change, behavior influences attitudes more strongly than the other way around. In spite of this, whichever way we choose to look at it, it is clear that there is a strong link between attitude and behavior, and as such pro-environmental interventions targeted at households should take cognizance of this connection.

Energy-Efficient Lighting

Energy efficiency means using less energy to provide the same service. For instance, a compact fluorescent bulb or energy-efficient bulb is more efficient than a traditional incandescent bulb as it uses much less electrical energy to produce the same amount of light. Similarly, an efficient refrigerator takes less fuel to cool the items in it than a less efficient model. It has been reported that Nigeria's energy consumption can be reduced drastically if households use energy-efficient fluorescent bulbs. GEF reported that households could save up to 67 % of the energy they use if the use of traditional fluorescent tubes and incandescent bulbs are discouraged. Compact fluorescents consume an average of 75 % less electricity than conventional incandescent lights, thereby reducing the overall demand for electricity and the resulting greenhouse gas emissions and environmental impacts. Energy-efficient bulbs may be more expensive at the point of purchase but help save more in the long run because they last longer than the incandescent bulbs. Household should be encouraged and supported to use energy-saving lighting and appliances.

Household Greening Program

This is a concept that suggests the need for households to green the environment. This concept suggests that each building could be built in such a way that there is room for green plantation within the surrounding so as to allow the plant to absorb carbon dioxide in the environment as well as reduce excessive flood by increased infiltration rate. Household greening program contributes to the mitigation of climate change impacts. In addition to storing carbon, trees planted in and around our environment especially urban areas and residences can provide much-needed shade in the hot season, reducing energy bills and fossil fuel use. It could also serve as resistance during severe rainstorm as well as reduce air pollution.

Adoption of Renewable Energy

Energy plays a leading role in any economy. It supports practically every other sector. Renewable energy comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are naturally replenished. This is an important area for intervention, since burning fossil fuels accounts for nearly 70 % of all electricity

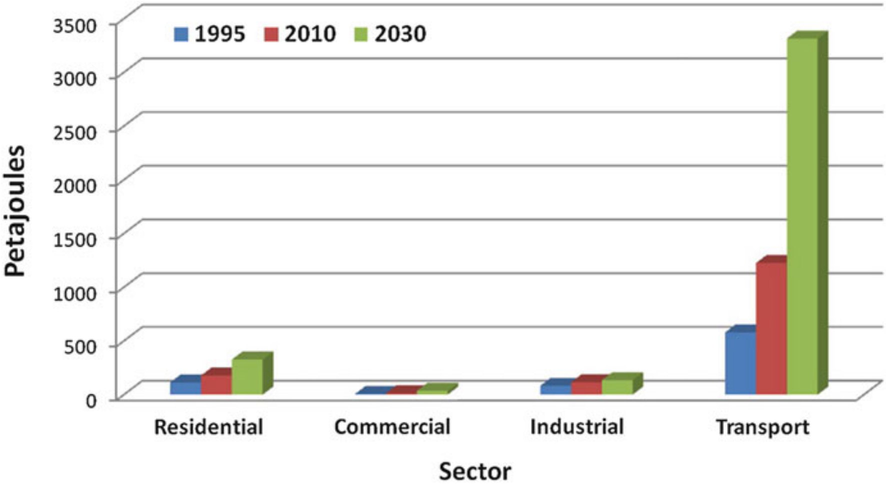

Fig. 4 Useful energy projections for Nigeria

generation (Energy Information Administration 2003a). With the abundance of renewable energy sources in Nigeria, the country could effectively mitigate the impacts of climate change. Individual household reliance on alternative sources of energy instead of relying solely on fossil fuel will likely contribute to climate change mitigation. Some of these alternatives include biogas, solar, and wind which are more environmentally friendly for cooking, heating, lighting, refrigerating, etc. It has been projected that residential energy demand for cooking and lighting will increase rapidly in the next decades, and as such integrating renewable energy into the energy mix at this level will be very important in the country (see Fig. 4). Education and awareness may, however, be needed to sensitize and orientate households toward the benefits of these renewable energy technologies.

Proper Use of Outdoor Lighting

Outdoor lighting is used at night to illuminate the surroundings. In Nigeria, however, most outdoor lights are often left on during the day. The proper use of outdoor lighting needs to be instilled among the populace. Lighting needs to be switched off when areas are unoccupied such as toilets, corridors, or even office areas out of hours. Outdoor lighting should only be on when needed. In Nigeria, where energy is generated mostly by burning of fossil fuel, leaving outdoor lights on when not needed increases consumption of fossil fuel and emission of carbon into the atmosphere. However, deployment of smart-metered electricity is expected to curb this behavior.

Altering Transportation-Related Behavior

Reducing vehicle emissions is often thought of as a technological challenge, with efforts going into the development of more efficient cars or fuels that produce fewer greenhouse gases per unit energy. Vehicles account for most of the carbon monoxide (CO) and a large share of the hydrocarbons (HC), nitrogen oxides (NO x), and particulates in major urban areas (ICCT 2013). In Nigeria, most automobiles imported into the country are old cars with inefficient fuel combustion system. It has been estimated that the export of used cars to developing countries and emerging markets worldwide will create additional pollution of 1.8 million tonnes of carbon dioxide (Bertinelli et al. 2005).

However, behavioral change could contribute to a low-carbon future by altering transportation-related behavior (Kollmuss and Agyeman 2002). Individuals could reduce travelling with personal cars, use video conferencing to attend meetings instead of travelling, join mass transit buses to office instead of taking personal car, etc. The proper maintenance and use of automobiles can help increase fuel efficiency and reduce energy consumption as well as pollution.

Household Energy Savings

Energy use at home contributes immensely to the total energy consumption of a country. The major energy-consuming activities in many homes in Nigeria are cooking, lighting, and use of electrical appliances (ECN 2005). Cooking accounts for a staggering 91 % of household energy consumption, lighting uses up 6 %, and the remaining 3 % can be attributed to the use of basic electrical appliances such as televisions and electrical irons (ECN 2005). Household activities can be tuned toward a low-carbon emission by encouraging individuals and households to turn off appliances instead of using standby mode and supporting the use of renewable energy, such as solar and wind energy. These activities will lead to low energy consumption at home and as such could help mitigate climate change impacts. Smart metering system that shows the amount of energy consumed daily could also be used to nudge household toward pro-environmental behavior.

The Business Sector

Climate change is affecting the ecosystems, marketplaces, and stakeholder needs in a remarkable way. This has created strategic new risks and opportunities for the business sector of the economy. For instance, many companies are now adopting pro-environmental innovative strategies so as to make them competitive in the global market. There is a large body of opinion that believes that an organization's culture plays an essential role in shaping the workplace behavior of employees in making them a low-carbon employee and hence widely considered to be crucial to an organization's performance. Organizations have roles to play in mitigating and adapting to the impacts of climate change in Nigeria. Industry and organizations use large amount of energy to power diverse range of manufacturing and resource extraction processes. Many industrial processes require large amounts of heat and mechanical power, most of which is delivered as natural gas, fuels, thermal, etc. In the past, most businesses in Nigeria have acted with little regard or concern for the negative impacts their production processes have on the environment. Many oil and gas companies in Nigeria were guilty of significantly flaring gas into the atmosphere until recently when the government has put some regulations in place to curb these activities. Subsequently, there are now an increasing number of businesses that are committed to reducing their damaging impact and even working toward having a positive influence on the environment. Below are suggested ways organizations can contribute to ensuring low-carbon future in Nigeria through the adoption of pro-environmental behavior.

Prompts/Green Messages

Prompting strategies are verbal or written antecedent messages that designate desirable target behaviors. Prompts are short messages used to elicit desirable behaviors. The message should be stated politely to avoid negative reaction. Geller et al. (1982) identified several conditions under which prompting strategies are most effective. Messages such as "Please, don't step on the Lawn," "Plant a TREE today," and "Switch off the Light" are simple messages that can remind people to mitigate climate change and as such preserve the environment. Prompt reminds people to make change again and again, until it becomes habitual. Prompts are most effective if specific and close to where and when the desired behavior occurs. Staats et al. (2000) found that office workers improved their energy-conserving behaviors (keeping thermostat settings consistent and putting off electrical appliances when not in use) immediately after an informational brochure was delivered. Later, other intervention components (posters and feedback) were added to maintain these energy-conserving practices.

Feedback

Feedback is vital to driving and sustaining change. Instead of understanding the changed behavior to be the end of the process, interventions should build in "feedback loops," i.e., opportunities to feed learning from the change process back into subsequent behaviors (Metz et al. 2007). Feedback should also be accounted for between individuals and organizations in networks and across society as a whole. A feedback strategy could involve providing information to staffs about their environment-relevant behaviors. Such data make the consequences of behavior (e.g., money spent, environmental degradation, or protection) more relevant and increase the likelihood of behavior change corresponding with the consequences. Some environment protection research that employed feedback strategy focused on household energy use and revealed that there was a modest and consistent reduction in energy consumption (Geller et al. 1982; Dwyer et al. 1993). Feedback reduces anxiety, encourages repetition of desirable behavior, and helps people know that they are making a difference. Feedback on energy use has been shown to have created savings of up to 20 % (Darby 2006).

Recognition

Organizations could engage in activities with the intention of reorienting the behavior of staff members toward reducing their carbon footprints. For instance, a form of recognition through monthly appraisal could help staff members in an organization to adopt energy-saving attitude. This could be in the form of award such as the "Most environment-friendly staff of the month." Also, offices can install a smart metering system which informs individual occupants how much they have consumed for the week and at what cost. Through this, individuals would become conscious of putting on appliances when they are not ready to use them.

Green Building/Zero-Carbon Buildings

Green building is defined as a structure that is environmentally responsible and resource efficient throughout a building's life cycle: from citing to design, construction, operation, maintenance, renovation, and demolition (World Bank Institute 2013). A green building is designed through architecture, materials, and fixtures to have a minimal impact on the environment. Improving the energy efficiency of organizational buildings through architectural building design will likely have the potential to reduce energy bills and building maintenance costs and more productive workers and increased building value. Organizations can adopt energy-efficient housing design principles with the aim of reducing the amount of energy consumed within the building. For instance, when the structure of a building adopts the use of fewer walls, it allows for reflection from outside, thereby reducing the need for artificial lighting during the day and access to ventilation resulting in less need of air conditioners.

Electrical Appliances Sharing

The concurrent use of electrical appliances in shared offices is a common sight in Nigerian offices. Appliances such as refrigerators, air conditioners, photocopy machines, fans, etc., can be shared among common-office occupants to reduce energy consumption. Organizations could inculcate in their employees the culture of putting appliances off especially when not in use, and they should encourage sharing of appliances among congruent office occupants.

The Role of Government

The government has a major role to play in the transition toward low-carbon economy. Government interventions in fostering human activities toward low-carbon emission can be of great benefit in terms of policy making, subsidizing the cost of energy-saving appliances, carbon tax on high emission appliance, ensuring importation of quality energy-saving appliances, and providing environmental education and regulatory guidelines.

Energy Policy

Issues such as energy crisis in the 1970s and concerns over climate change impacts have attracted the interests of policy makers in supporting incentives for electricity from renewable energy sources (Fischer and Preonas 2010). The IPCC has reported that apathy for fossil fuel could lead to the promotion of alternative sources of energy. Renewable energy technologies are being rapidly commercialized in developed countries. In 2012, about 26 % of the global final energy consumption came from renewable energy and supplied 21.7 % of global electricity (REN21 2013). During the 5 years from the end of 2004 through 2009, worldwide renewable energy capacity grew at rates of 10–60 % annually for many technologies. Nigeria is yet to harness this independent source of generating income for the economy and in solving the electricity crisis ravaging the country. However, the Energy Commission of Nigeria has developed a Renewable Energy Master Plan for the country. The main objective of the master plan is to promote clean, reliable, secure, and competitive energy supply into the national energy mix as well as meeting up with the national sustainable development agenda. The main goal of this project is to reduce projected energy use by 20 % by 2020 and meet 20 % of the country's electricity needs with renewable energy sources by 2020. This initiative combines energy efficiency, conservation, and renewable energy resources to meet future increase in energy demand while reducing its dependence on nonrenewable resources. As part of the implementation of this initiative, NNPC set up a Renewable Energy Division (RED) to develop private sector-driven investments in ethanol production as alternatives to fossil fuels. However, there is still a lot to be done in terms of national implementation, capacity building, and strong institutional framework to support this policy.

Transport Policy

In Nigeria, two main types of environmental policies could be proposed to alter or modify people's transportation behavior. These could be in the form of information and regulatory measures. In Nigeria, regulatory measures should include rebuilding and reintroducing rail transport in order to reduce the present massive use of buses for long distance travel, restructuring urban transportation to introduce car-free zones and urban mass transit system, subsidizing urban mass transportation, and improving the infrastructure for cycling and walking as well as green parks.

In addition, informational measures could be achieved through mass media by discouraging the use of personal cars or making it less desirable by raising awareness of the problems caused by carbon emissions from multiple cars on the road. Awareness should also be created on using mass transit buses, discouraging frequent travels, encouraging the purchase of eco-friendly vehicles, and changing in driving behavior (improved vehicle maintenance, fuel-efficient driving, and using telematics to provide information on traffic situations) (Jalel et al. 2011).

Role of Information/Communication

One enduring assumption of much public policy in the environmental domain claims that when provided with information, people will change their behavior toward low-carbon society. Human beings have the capacity to use information-based approaches to change significant others' behavior. Awareness creation can play a big role in changing the attitude of Nigerians on the need to develop a low-carbon economy toward mitigating and adapting to the impact of climate change.

Nudging: In recent times, many policy makers have incorporated the use of nudges on pro-environmental behavior change strategy. "Nudges" have been defined as “any aspect of the choice architecture (the context in which people make decisions) that alters people’s behaviour in a predictable way, without forbidding any options or significantly changing their economic incentives” (Thaler and Benartzi 2008). For instance, while removing incandescent bulb from the point of sale in a supermarket is a nudge, banning it or significantly raising its price is not (see Table 1).

Carbon Tax

The government can introduce environment-related tax reduction for organizations with less carbon emission during production/manufacturing in order to encourage organizations to adopt such production processes. For individuals that decide to leave their cars at home to use public transport, the government can subsidize mass transit buses and introduce congestion charges and subsidies for alternative fuel vehicles to encourage such activities. The Nigerian government could encourage businesses to reduce their carbon footprint by providing grants to invest in energy-efficient equipment and supporting the private sector for renewable and clean technology projects.

Energy-Efficient Equipment Standardization

The government has the obligation to ensure that the quality of energy-efficient appliances and equipment imported into the country is of high standard. If the standard of these appliances can be assured to be of good quality, it will encourage buyers and users to take the pain of paying more for these appliances. Also, the government can help subsidize these appliances in order to increase the willingness to buy. Government policies can be directed to encourage the importation and local production of energy-efficient light bulbs so as to reduce the cost of these bulbs.

Penalties for Deforestation

Strict penalties should be in place for the cutting down of trees unjustly. Deforestation should be discouraged as much as possible, and human activities that encourages the cutting of trees for survival and economy purposes could be diversified. Planting of trees will help increase mitigating climate change impacts. Trees are 50 % carbon. When they are felled or burned, the CO_2 they store escapes back into the air. According to the UNFAO (2006), about 13 million hectares of forests worldwide are lost every year, almost entirely in the tropics. The government can even take up the initiative of rewarding tree planting as it is done in the developed world. A nationwide program of reafforestation can also be developed. A case in point is the “Igi Iye” reafforestation initiative of the Osun State government in Nigeria.

Gas Flaring Penalties

Despite the legislative framework pegging the deadline for gas flaring of Nigeria’s petroleum sector on December 31, 2012, the Nigerian National Petroleum Corporation recently stated that gas flaring has only dropped by 15 % as of 2013 (Yakubu 2013). Nigeria flares volumes of carbon daily as part of its oil exploration activities.

Gas flaring has raised temperatures and rendered large areas uninhabitable. According to the World Bank 2012 Report on Global Gas Flaring Reduction partnership (GGFR), Nigeria is second next to Russia in terms of gas flaring and has remained so over a period of 5 years between 2007 and 2011. Nigeria, the highest producer of gas in Africa, loses about $1.789 billion or N286.24 billion to gas flaring annually (Deziani 2010). Due to the contained methane and carbon dioxide, Nigeria's gas flaring contributes more to global warming than all the other emissions in the whole sub-Saharan Africa. The Nigerian government needs to double its effort in addressing this situation by ensuring compliance with regulations and issue stiff penalties to nonadhering companies.

Conclusion

Climate change is a challenge that requires effort across individuals, organizations, and government levels. This chapter discusses the human behavioral contributions to climate change issues. It also addresses both the psychological and contextual drivers of these concerns in Nigeria. Pro-environmental behaviors are multifaceted, context specific, and affected by numerous factors, many of which need to be addressed simultaneously to facilitate the desirable change. Policies that aim to encourage pro-environmental behavior need to reflect these intricacies. As outlined above, there are a number of specific actions that key stakeholders can undertake to heal the environment and "green" their lifestyles. However, there is the urgent need to collectively focus on a more limited set of pro-environmental behavior goals for the purpose of public policy and awareness creation. This is important as it will ensure that a clearer focus would reduce some of the current confusion over conflicting information about what people can or should do as well as establishing a baseline against which progress could be assessed.

Policy Implications

In view of the issues raised above, the effectiveness of any strategic policy framework to address the effects of climate change in Nigeria both in the medium and longer term depends largely on achieving changes in behavior and attitudes among the key stakeholders. This will involve changing behavior by the households, government, and the practitioners in the business sector. In addressing these issues, some of the policy strategies should involve the widespread adoption of more sustainable options over the conventional alternatives, increased awareness about climate change, more increased support for the development of renewable energy infrastructure (such as waste to energy plants, wind farms, and related transmission infrastructure), and cumulative small-scale actions in individual homes (e.g., waste reduction, energy efficiency measures). This chapter reiterates that the specific objective of low-carbon future for the country should be the development, adoption, and implementation of sustainable policies, action plans, strategies, and regulation that promote pro-environmental behaviors as well as enhancement of increased investments in sustainable energy utilization via energy planning, nudging, regulation, enabling carbon tax, and improved public-private partnership options. These initiatives, if properly implemented, will stimulate the development of pro-environmental behaviors and implementation of environmentally sustainable policies, strategies, and regulation.

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Universal Metrics to Compare the Effectiveness of Climate Change Adaptation Projects

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Abstract

Adaptation to climate change is increasingly supported through international financing. In contrast to mitigation, where the effectiveness of policy action can be measured through the metric "tonnes of CO_2 equivalent reduced," no universally accepted metric for assessment of adaptation effectiveness exists. Without such a metric, adaptation finance vehicles such as the Adaptation Fund or the Green Climate Fund encounter challenges when trying to compare the adaptive effect of projects in order to achieve an efficient allocation of their funds. First experiences with adaptation funding show a tendency to avoid final impact metrics. This might lead to a backlash against adaptation funding by electorates in industrialized countries if adaptation funding cannot show clear results. This report assesses two possible candidates for generic adaptation effectiveness metrics: (1) wealth saved from climate change impacts and (2) disability-adjusted life years saved (DALYs), which are widely used in public health policy analysis. Apart it is proposed to use no-harm assessments to evaluate environmental and cultural impacts of adaptation projects. The authors discuss uncertainties encountered in applying these metrics, including the uncertain link between commonly reported intermediate indicators and our metrics and ideas to handle such, e.g., the use of regularly updated methodologies and agreed climate and economic models.

Keywords

Adaptation • Climate change • Effectiveness • Metrics • DALYs • Adaptation Fund • Green Climate Fund

Introduction: Climate Change and the Emergence of Adaptation Policies

Burning of fossil fuels and other human activities have led to an increase of atmospheric CO_2 concentrations from around 280 parts per million (ppm) in the preindustrial era to more than 400 ppm in 2014. Global temperature increase from preindustrial levels has already reached more than 0.7 °C, and temperatures are expected to further rise 1.1–6.4 °C until 2100 leading to sea-level rise, melting of ice, and changes in wind and precipitation patterns (Solomon et al. 2007).

Due to these alarming trends, anthropogenic climate change has been on the agenda of the international community for the last two decades. A series of multilateral treaties tries to address the problem. The United Nations Framework Convention on Climate Change (UNFCCC) has the ultimate objective to achieve a "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner"

(Art. 2, UNFCCC 1992). The Kyoto Protocol to the UNFCCC, agreed in 1997, has introduced legally binding emission targets for industrialized countries and an array of market mechanisms to reduce the costs of reaching those targets, including the Clean Development Mechanism (CDM), which allows the generation of greenhouse gas emission credits through emission reduction projects in developing countries.

While adaptation to the adverse effects of climate change has generally taken a backseat to mitigation in international climate policy, parties to the UNFCCC and the Kyoto Protocol have increasingly realized that adaptation is vital in order to reduce the impacts of climate change that has already taken place or to which they are committed. Therefore, in 2001 the UNFCCC has set up two funds for adaptation financed by voluntary contributions of industrialized countries – the Least Developed Countries Fund (LDCF) and Special Climate Change Fund (SCCF), which are managed by the Global Environment Facility (GEF). In 2007, parties of the Kyoto Protocol established the Adaptation Fund (AF) with a creative system of financing. The AF receives 2 % of all emission credits (CERs) issued under the CDM, i.e., an in-kind tax on emission credit transactions. The CERs are then sold by the Trustee of the AF (i.e., the World Bank) in tranches. However, attempts to extend this tax to other market mechanisms have failed due to the resistance of Russia and other countries in transition.

The unexpected success of the CDM has led to a substantial inflow of finance to the AF. By 2014, 1.5 billion CERs had been issued, and the AF thus received 30 million CERs. Revenues from sales of CERs have reached about 190 million USD (Adaptation Fund 2013). This is a large sum raised in only 5 years compared to the 270 million USD the LDCF and the SCCF have raised together in 10 years (HBS/ODI 2011).

Besides these existing funds, the negotiations about a post-2012 climate policy regime have led to the commitment of industrialized countries to provide 30 billion USD of "fast start" financing to developing countries within the period 2010–2012. Around 20 % of these funds are allocated toward adaptation (analysis according to Nakhooda et al. 2013; UNFCCC 2011; VROM 2011). Additionally the Green Climate Fund (GCF) has been established as an operating entity of the financial mechanism of the UNFCCC, also being responsible for the funding of adaptation activities. It is in the implementation phase, and the GCF Board has been developing modalities and procedures since 2012.

Currently, projects financed with international adaptation funding are not assessed according to comparable metrics. The guidelines used by the AF's Project and Programme Review Committee (PPRC) entail many criteria for the assessment of projects, such as economic, social, and environmental benefits, meeting national standards, cost-effectiveness, and arrangements for management and monitoring (AFB 2010). These criteria are very general and do not allow to compare the concrete adaptation effect of project proposals. As another example, the GEF neither uses efficiency indicators nor global targets for adaptation projects (GEF 2008).

From an economic point of view, it would be desirable to maximize the adaptive benefit achieved with the available financial resources for adaptation. The limited level of these resources compared with the adaptation needs, which are three orders of magnitude higher – as calculated by Parry et al. (2009) – makes this even more urgent. This implies that funds need to be allocated to those projects/programs that bring the highest benefits to economies, people, and the environment. Clear metrics of the "adaptive benefit" and an evaluation of proposals with regard to these metrics are required.

This paper tries to identify universal metrics for adaptation benefits and test them by assessing existing adaptation projects. First attempts in the literature to use universal indicators are analyzed, and two universal metrics are proposed, which synthesize three existing approaches: saved wealth and saved health. As these metrics depend on long-term results of the projects, it is discussed how (measurable) outcome indicators can be linked with them. To illustrate and test this approach, it is applied to specific examples and conclude.

Lack of Universally Accepted Metrics: Opportunities and Challenges

For projects mitigating GHG emissions, a universal consensus has emerged that their effectiveness is to be measured in terms of tonnes of CO_2 equivalent reduced. This metric is used for all project-based mechanisms and allows calculating the efficiency of projects in terms of currency units spent to achieve 1 t CO_2 equivalent reduced.

Regarding adaptation, the situation is much more diffuse as adaptation policies just start to emerge and even basic concepts of adaptation are still contested. The 4th IPCC assessment report (Adger et al. 2007) is lamenting the lack of globally accepted and agreed indicators for vulnerability and adaptive capacity, while also noting that there is no consensus on the usefulness of such generic indicators. A 2008 workshop on adaptation metrics has not managed to identify universal metrics but only stated that good adaptation metrics should be comparable but also context specific and developed in participatory processes (IGES and World Bank 2008). The lack of universal metrics has continued until today (UNFCCC 2010b).

The skepticism against global indicators and the call for bottom-up approaches may be linked to the disciplinary background of many adaptation researchers and stakeholders: qualitative, case study-based social science. In this vein, e.g., Klein (2009) argues that vulnerability cannot just be defined by technical experts as any definitions involve value judgments. In his view, a definition rather has to evolve through a "consultative, stakeholder-driven process."

Economists have not managed to clearly specify adaptation metrics either. While there have been several influential studies on the economics of adaptation (Agrawala and Fankhauser 2008; World Bank 2010), they have concentrated on highly aggregated adaptation costs and did not assess how effectiveness of projects could be measured. In parallel to the elaboration of this study, further literature has been published that aims at universal metrification of adaptation benefits. Schultz (2012) has developed a concept on how to finance adaptation with a vulnerability reduction credit mechanism. Based on the polluter's pay principle, Schultz derived

Table 1 Opportunities and challenges of universal metrics for adaptation

	Opportunities	Challenges
Political view	Shared vision of adaptation goals	Choosing indicators will make some nations better off than others; agreement is therefore difficult (Hinkel 2008)
Ethical view	Transparent criteria for projects	Value judgments are needed (Hinkel 2008; Klein 2009)
Economic view	Ex ante identification of promising projects (Noble 2008), ex post monitoring (Noble 2008), ex post adjustment (Hallegatte et al. 2011), potentially allocation of funds (Butzengeiger et al. 2011)	Measurement of indicators is uncertain (Hallegatte et al. 2011; Hinkel 2008); important metrics are qualitative (IGES and World Bank 2008)

the idea of a universal compliance scheme that either leads to mitigation or adaptation activities. This fungible structure works with credits that quantify the vulnerability reduction through adaptation projects. These credits get monetized by annual calculation of the costs of climate change impacts per tonne of CO_2. Finally the polluter chooses if he complies through mitigation or adaptation credits. However the rudimentary model still lacks a detailed description on how both the climate change impacts and the vulnerability reduction can be quantified properly.

Baca (2010) discusses a market-based adaptation approach through a CDM-like system that allows polluters to generate emission allowances through adaptation activities. Hereby National Adaptation Plan of Actions (NAPAs) deliver a prioritization of required projects, and the mechanism tenders these projects through reverse auctioning. As reward the project developer receives emission rights (see Baca 2010, p. 10ff). However, a detailed description of the metrics to allocate emission rights to adaptation projects is missing.

A UNFCCC (2010a) review of approaches for assessing costs and benefits of adaptation options clearly shows that most approaches focus on either adaptation costs or vulnerability/risk management. Only two options clearly compare costs and impacts: cost-benefit analysis (see, e.g., ECAWG 2009; Moench et al. 2009) and cost-effectiveness analysis. This situation can be compared to the early days of assessing effectiveness of emission reduction, where the metrics to compare the effect of different greenhouse gases were contested.

What may be the reasons for the lack of global indicators, apart from disciplinary backgrounds? Table 1 shows that universal metrics bring both opportunities and challenges. On the political side, agreed adaptation metrics may help to improve the shared vision in the climate change regime. However, political agreement may be difficult as some metrics leave some nations better off than others. Ethically, universal indicators may bring transparency in assessing adaptation projects, but some scholars argue that defining universal adaptation metrics will include value judgments, which raises the question which stakeholders are involved in defining the metrics (Hinkel 2008; Klein 2009).

The largest advantages of universal indicators are on the economic side. Promising projects and programs may be identified ex ante, and monitoring may allow for ex post adjustments of projects (Hallegatte et al. 2011; Noble 2008). The main challenge here is that the prediction and measurement of indicators for adaptation is highly uncertain (Hallegatte et al. 2011; Hinkel 2008) given the missing knowledge on climate change and its impacts, as well as the development and influence of other socioeconomic variables. Hinkel (2008) argues that this makes outcome indicators for adaptation non-promising and calls for using process indicators. Hallegatte et al. (2011) are more optimistic by saying that cost-benefit analysis is a useful tool as long as uncertainty is satisfactorily addressed.

Concluding, the opportunities of universal adaptation metrics justify a closer look at possible metrics. However, the challenges should not be forgotten: while the political and ethical issues are not part of this chapter, it is explored how uncertainty could be addressed.

Synthesizing Three Approaches for the Effectiveness of Adaptation Projects

When searching for a universal metric for the effectiveness of adaptation projects, three existing approaches are particularly relevant: vulnerability assessment, cost-benefit assessment, and cost-effectiveness assessment.

Reducing vulnerability is the shared goal of many adaptation programs and is anchored in several UNFCCC documents. However, vulnerability is not universally defined, and many different vulnerability indicators and assessment exist: the Disaster Risk Index, the impact vulnerability index, the Disaster Deficit Index, UNDP's Vulnerability Reduction Assessment scorecard, and further vulnerability indicators (GEF 2008). Politically, it has never been possible to agree on a specific indicator. Therefore, vulnerability has to be incorporated in any adaptation metric system, but developing a new vulnerability (benefit) index will not solve the problem.

Another starting point for universal effectiveness metrics is cost-benefit analysis simply looking at economic benefits of adaptation projects. For example, Moench et al. (2009) discuss the appropriateness of cost-benefit analysis coupled with intense stakeholder participation and apply cost-benefit analysis for a series of case studies in India and Pakistan. In a bold study, the Economics of Climate Adaptation Working Group (ECAWG 2009) criticized the lack of a systematic way of estimating climate risks and the absence of an overarching methodology to facilitate comparisons between the risks posed by different hazards and in different geographies. It developed a methodology that gave rise to adaptation benefit-cost curves and applied it to China, Guyana, India, Mali, Samoa, Tanzania, the UK, and the USA. Such cost-benefit analysis can be criticized for neglecting nonmonetary benefits such as health, which is recognized by Moench et al. (2009).

Cost-effectiveness analysis, as the third approach, includes nonmonetary or difficult-to-monetize benefits as well: it identifies the least-cost method of reaching a prescribed target or risk reduction level. For instant, it is widely used in the literature on public health (see, e.g., Detsky and Naglie 1990). On the downside, cost-effectiveness analysis for adaptation was only applied in a sectoral context until now. Universal metrics are missing, which blocks comparison of effects between different areas.

With the indicators to be proposed, the intention is to synthesize the three approaches: while aiming to avoid the monetary-only approach of cost-benefit analysis, global comparability shall be guaranteed, currently missing in cost-effectiveness studies focusing on. Furthermore, vulnerability should be captured by the metrics as well.

Reasons for Moving Beyond a Pure Economic Approach

Theoretically, the effects of adaptation projects could be measured in monetary terms. This theoretical approach underlies the cost-benefit analysis approach of ECAWG (2009) which leads to a "benefit-cost curve" for adaptation projects. However, a substantial share of the benefits of adaptation projects is the avoidance of direct impacts on human life and health. Then the challenge arises on how to value human life and human health. Fankhauser and Tol (1998) argue that "values of a statistical life" embodying people's attitude to mortality risks should be used for that valuation. These values strongly depend on the income of the person and thus are substantially lower for a poor person than that of a rich person, varying by a factor of 15 between China and OECD countries (Fankhauser and Tol 1998). Other studies show a range of value of a statistical life of up to over 20 million USD (Viscusi and Gayer 2003; Viscusi and Aldy 2003), and the valuation is country, income, and age dependent (Aldy and Viscusi 2008; Viscusi and Aldy 2003). This approach thus became heavily contested in the elaboration of the 2nd Assessment Report of the IPCC, when developing country authors and policymakers strongly attacked what was seen as "Northern arrogance" (described condescendingly by Tol 1997). As a response to the controversy, Fearnside (1998) suggested to separate human lives and property values. In our view, Fearnside's approach should be followed to avoid endless political debates about an equitable valuation of human life and health. This is also in line with UNFCCC (2010a) which stresses that pure cost-benefit analysis "fails to account for those costs and benefits that cannot be reflected in monetary terms, such as ecological impacts and impacts on health." Thus it is differentiated between monetary and human life-/health-related benefits, in the form of two indicators.

Saved Wealth (SW)

Accumulated income not spent for consumption gives rise to wealth; this can include productive assets and other forms of property (e.g., real estate and precious metals). The indicator specifies wealth protected by an adaptation project against destruction by climate change impacts. For cross-country comparisons, purchasing power parity should be used.

When assessing the wealth benefit of an adaptation project/program, one can use two different concepts: absolute wealth and relative wealth (assessed on an aggregate or individual level).

"Absolute wealth saved" is similar to the approach of cost-benefit analysis as it measures the absolute wealth saved. The concept is straightforward but does not take into account differences of wealth, which might be crucial for overall resilience: regions with a higher wealth level would be favored. The indicator would be currency units.

In the concept of "relative wealth saved (aggregated assessment)," the absolute wealth saved by the project is divided by the total wealth of the region, city, or community. This allows accounting for differences in average wealth but does not yet cover the distribution of wealth within the project region. The indicator would be percent wealth saved times population.

In an alternative specification, "relative wealth saved (individual-level assessment)," the affected number of people and their individual wealth shares protected by the adaptation project are calculated. In contrast to the aggregate assessment of relative wealth, the relative wealth is assessed on an individual level and then summed up. Data challenges are massive as every person has to be accounted individually. This might only be possible in countries with a highly efficient tax administration and no data confidentiality restrictions regarding personal fortunes. Given data constraints, the concept is more realistic, when using a city or community as individual unit: in this case, the total relative wealth saved consists of the sum of the relative wealth saved in each city or community, rather the sum of the relative wealth saved per individual.

Advantages and disadvantages of the different approaches are described in Table 2.

The relative wealth concept (on an aggregated basis) seems to be most adequate from a vulnerability perspective, taking data availability into account. The more local the geographical scale of this relative wealth concept is, the better the concept addresses vulnerability. However, from an economic perspective, the absolute wealth concept is most appropriate as it measures the overall wealth savings. It is thus proposed to include both relative and absolute wealth savings in the saved wealth indicator in order to balance vulnerability and economic benefits.

For determining the potential of an adaptation activity to save wealth, one needs to consider autonomous developments of the wealth of the relevant region during the project duration. Demographic and/or economic developments over time will lead to changes of property and therefore wealth under a baseline scenario.

A time-related discounting of wealth in the region impacted by an adaptation activity should take place in order to reflect inflation as well as autonomous decrease of the economic value of infrastructure and hardware over time (capital consumption, standard accruals). Discounting is also important to achieve comparability of adaptation projects with different lifetimes.

Table 2 Approaches to measure saved wealth

Concept	Description	Advantages	Disadvantages
Absolute wealth saved	Wealth benefit in absolute terms	Relatively easy to measure	Benefits richer countries, does not reflect vulnerability
Relative wealth saved (assessed on an aggregate level)	Wealth benefit relative to overall assets of a nation, multiplied with population	Allocates (adaptation) funds to poorest countries (or regions, cities, communities)	Benefits not necessarily poorest or most vulnerable persons within a country
Relative wealth saved (assessed on an individual level)	Wealth % saved per person; individual percentages are summed up	Close to vulnerability	Data access difficult in case of individualized approach

Figure 1 below visualizes the effects of autonomous development of wealth in the region over time and of discounting on saved wealth.

The total wealth that can theoretically be saved by an adaptation activity is the discounted wealth that would be lost by climate change-induced events during the technical lifetime of the adaptation project/program. To calculate this, one needs a frequency distribution function of climate change impacts for the duration of the project (see Moench et al. 2009 for the first conceptualization of such frequency functions, here shown in Fig. 2).

Using the approach of the frequency distribution function, saved wealth (SW_p),[1] for a disaster risk reduction adaptation project, can then be calculated as

$$\mathrm{SW}_p = \sum_0^i \cdot \frac{\mathrm{MDP}_i}{(1+\mathrm{r})^i} \cdot \mathrm{DS}_i \cdot p_{\mathrm{occ},n,i} \tag{1}$$

where

$0\ldots i$: years of duration of adaptation project
MDP_i: maximum damage potential from climate change in year i
DS_i: share of discounted MDP damaged by event forecast in year i
$p_{\mathrm{occ},\,n,i}$: probability of occurrence of a certain damage event n (increase of risk due to climate change) in year i
r: discount rate to be applied to the project

From a purely economic perspective, total damage should be assessed and differentiated by whether it is due to baseline climatic variability or due to events that can be linked to climate change. For projects financed by third parties, only the differential damage due to climate change should be covered. However,

[1]Here, for simplicity just the absolute and not the relative wealth savings are calculated.

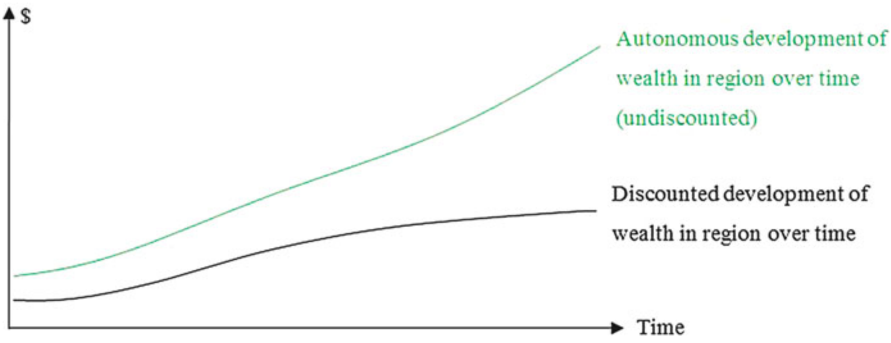

Fig. 1 Change of wealth over time and discounting

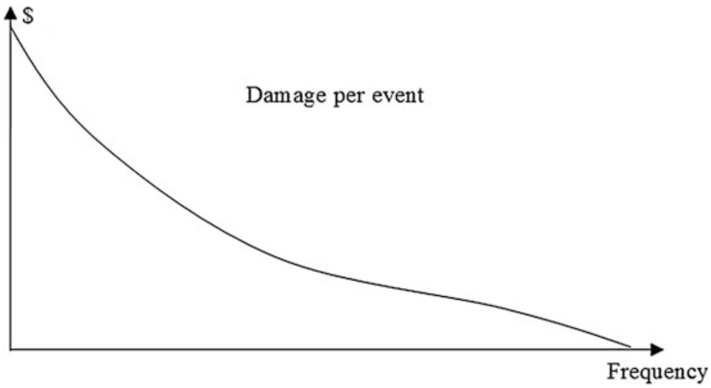

Fig. 2 Frequency distribution function of expected damage

differentiation of impacts from baseline climate variability, climate change, and autonomous adaptation is likely to be extremely difficult.

Saved Health (SH)

As discussed above, valuation of human life is fraught with ethical challenges and thus should be avoided, especially if comparing industrialized and developing countries. This section explores the concept of disability-adjusted life years saved (DALYs), which was introduced in 1993 by the World Bank (1993), and has since then been systematically utilized – inter alia by the World Health Organization (WHO) in the "Global Burden of Disease Concept" (GBD), which provides a comprehensive and comparable assessment of mortality and loss of health due to diseases, injuries, and risk factors for all regions of the world (WHO 2010a). It is a concept to quantify the burden of disability and death, expressed as the number of years lost due to disability and early death:

$$\mathrm{DALY} = N \cdot L + \sum_i I_i \cdot \mathrm{DW}_i \cdot D_i \quad (2)$$

where

N: numbers of deaths
L: standard life expectancy at age of death (in years). Here, an ethical issue is the choice of the region. From an equity viewpoint, the average global life expectancy should be chosen, whereas from a comparative economic view, the locally applicable life expectancy would be preferred:
I_i: cases of disease/injury i
DW_i: disability weight of disease/injury i
D_i: average duration of disease/injury i (years)

The weight factor DW reflects the severity of the disease or injury on a scale from 0 (perfect health) to 1 (dead) and has been estimated by WHO (2010b) for a wide range of diseases.

Taking the frequency distribution function approach described above (see Fig. 2), for assessing the saved health for a particular adaptation activity, one needs to define a health damage frequency distribution function that quantifies the typical health damages of a given event and its frequency.

Environmental and Cultural Benefits

The valuation of nonmonetary environmental and cultural benefits is fraught with conceptual difficulties (see, e.g., Bockstael and Freeman 2005). Fankhauser et al. (1998) describe the differences in willingness-to-pay and willingness-to-accept valuation approaches for such benefits. In our view, the challenges of this approach are so high that a simple “no-harm” rule should be followed for the evaluation of adaptation projects. For projects of certain minimum sizes, a qualitative evaluation system comparable, e.g., to standard environmental impact assessments (EIA) could be applied to check whether an adaptation project has negative impacts regarding biodiversity and soil, air, and water pollution. Likewise, projects should check whether cultural heritage, be it material or immaterial, would be jeopardized. Generally, an approach could be imagined where the host country of foreign-funded adaptation projects approves the ecologic and cultural sustainability, in a procedure akin to today’s approval of CDM projects.

Dealing with Uncertainty

Obviously, introduction of the impact indicators requires highly challenging data collection exercises. Given the uncertainties of future climate change and economic development, coordinated approaches are required to prevent ad hoc choices of data

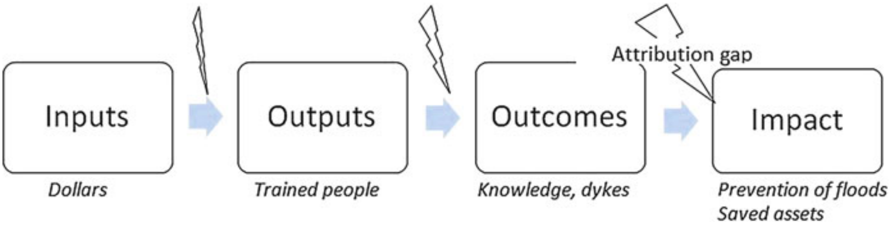

Fig. 3 Linking adaptation project outcomes with impacts (own graph)

that are favorable for the project developer. At first, a political agreement on the downscaled climate models used for derivation of the frequency curves of climate impacts is required. In a similar vein, forecasts for economic development need to be made consistent to allow a comparable wealth forecast. While the use of such indicators is certainly a non-perfect solution given data constraint, it is preferable to a situation where projects are evaluated according to a heterogeneous set of (often project-specific) indicators.

Links Between Intermediate and Final Indicators

As final metrics, such as saved wealth and health, are difficult to measure, multilateral institutions such as the GEF (2008) and the AFB (2010) use intermediate (so-called output and outcome) indicators for climate change adaptation projects, e. g., institutional capacity or awareness (see Fig. 3). How are they linked to our proposed metrics? Adger et al. (2007) emphasized the relevance of all outcomes shown in Fig. 3 for adaptation and reducing vulnerability. The only one not explicitly mentioned as factor contributing to adaptation is ecosystem resilience. Generally, the literature is not very explicit about the size of the effects, while it becomes clear that only few effects are direct such as the use of new dam technology on saving wealth. Most links are rather indirect and require an intermediate action (e.g., the climate change information provided by an early warning system has to be put into use via disaster response actions). Furthermore, several intervening factors may reduce the strength of the theoretical link, e.g., change in socioeconomic circumstances.

A key issue for output-outcome-impact links is the time horizon. The longer an adaptation intervention lasts, the higher is the risk that an adaptation, appropriate in the short and maybe medium term, turns into maladaptation. Maladaptation may be defined as "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups" (Barnett and O'Neill 2010). For example, an adaptation project may change the design level of water supply for an irrigation system based on the estimate of the increased river flow due to glacial melting in the catchment area. As long as the glacial melting continues, the project contributes to adaptation, but once the glaciers have vanished, the irrigation system will be oversized and a water supply crisis will erupt. So in the long term, the link between outcome and impact indicators will be weakened.

A response to the risk of maladaptation could be to introduce an indicator that defines the risk of long-term maladaptation and to check this indicator periodically, triggering an adjustment in the adaptation project design. In the context of the irrigation project case, the indicator would be glacier volume in the catchment area and the probable date of glacier disappearance. If, for example, the glacier disappearance would be less than a decade in the future, a downsizing of the irrigation system would be started combined with an economic diversification strategy.

Dealing with Causal Links in the Future

The assessment of the existing knowledge and the use in practice has shown that outcome-impact links are highly uncertain and prone to risks. Furthermore, new scientific evidence may change the intensity or even direction of the expected effects. Therefore, any approach to estimate effectiveness of adaptation projects with global indicators has to apply a flexible approach allowing for permanent adaptation, as also called for by Hallegatte et al. (2011).

A four-pronged approach is proposed to guarantee flexibility. First, as start, the intermediate steps between outcome and impact indicators have to be elaborated more in detail. This idea is similar to the concept of secondary outcomes as proposed by the AFB (2010). Secondly, the intervening variables that enable or prevent an effect from taking place have to be identified and potentially measured or estimated. Third, all links and assumptions are to be seen as best assumption for the time being. As soon as new scientific evidence is available, the assumptions have to be changed. Fourth, the intermediate indicators as set out here are to be complemented or replaced by other indicators, if scientific studies show the importance of further indicators. In the end, various approaches and ways may lead to the desired results. Certainly, the current eight or nine indicators used by the GEF and the AFB are too broad if applied to specific sectors. An example of refined indicators per sector is given by Schönthaler et al. (2010).

How can this encompassing and flexible approach be achieved institutionally? One idea is to elaborate specific causal-chain methodologies for each sector or even better for each project type, similar to the methodologies in the CDM (see Michaelowa 2005). Methodologies could be elaborated by the AF itself, country program managers, international organizations, or academic experts. Each methodology would have to be approved by the AFB, and revisions can be proposed by stakeholders or the AFB itself at any time, as long as they are based on the newest scientific findings.

Application of Framework to Concrete Projects

In order to illustrate and test the applicability of the proposed impact metrics, five adaptation projects are assessed. For the assessment, information in the official project proposals downloaded from the Adaptation Fund website (AFB 2011) is

Table 3 Assessment of five adaptation projects against proposed metrics (own assessment, using project documents from AFB (2011))

Metric	Unit	Project A	Project B	Project C	Project D	Project E
Beneficiary intensity	Persons with improved livelihoods/ million USD of adaptation funding	22,600	Not reported	950	50	26,850
Wealth saved – absolute	USD saved per annum/USD	6	Not reported	0.3	0.7	Not reported
Wealth saved – relative	# of personal wealth saved/ million USD	5,000	Not reported	700	75	[530]
Health saved	DALYs/million USD	Not reported	Not reported	Not reported	Not reported	120,000
Environmental benefits	[Qualitative scale]	Positive	Positive	Positive	Slightly positive	Positive

used. No external sources were used to verify the information, which means that the following results are illustrative.

Table 3 shows the predicted benefits of the five projects when assessed against our metrics.

Relating to *absolute saved wealth* (measured in annual USD saved per USD of requested grant), project A has the highest score, followed by D and C. The other two projects did not give any information on absolute saved wealth. Where absolute wealth benefits were given, justification was mostly scarce and the assumptions were not fully specified. Projects report saved wealth not over the total project lifetime but only per year, which raises the question how long a project will last.

Relative wealth saved is measured here in number of persons whose personal income is saved per million USD of requested grant. This relative wealth number was calculated as share of average income saved multiplied with the number of beneficiaries. Therefore, aggregate wealth numbers were used, as individual wealth numbers are not available. Average income was assumed to equal the national GDP per capita using data from the World Bank (2011).

Project A scored highest before projects C, E, and D. For project B the factor could not be calculated as numbers of beneficiaries and absolute saved wealth are missing. Interestingly, project C is performing better on this relative wealth indicator than project D, whereas it is the other way round in case of absolute wealth saved. The reason is both higher number of beneficiaries and lower income in case of project C.

Finally, when assessing *health saved*, measured in DALYs saved per million USD of requested grant, no data has been identified in the project documents. For project E the number of beneficiaries with malnutrition is known, and assuming a disability weight of malnutrition of 0.3, one can estimate the number of DALYs saved.

The numbers given here would indicate that projects A and E perform highest on the adaptive benefit, before projects C and D. Deciding on the exact rating for the adaptive benefit will depend on the political weighting of different indicators. Environmental no-harm is never a critical issue, as all projects show significant positive environmental benefits.

This illustrative analysis of five adaptation projects has revealed two major problems: missing data on impact indicators and unclear assumptions. For making global metrics feasible, AF projects would have to be obliged to report on how they perform on promising impact indicators to assess their feasibility before introduction.

Conclusion

In contrast to climate change mitigation, the effectiveness of adaptation projects so far is not evaluated according to universally accepted metrics. As adaptation so far was the “step child” of the climate regime, it was mainly treated as a by-product of development assistance, and thus the evaluation procedures of development assistance projects have traditionally been used. These procedures are based on a “results chain,” with a series of indicators from input to project impacts.

To avoid a situation where adaptation funding is essentially distributed in a “first come, first serve” mode, it is imperative to agree on one or a set of indicators that allow a choice of adaptation projects according to their effectiveness per unit of money invested. A single, universal indicator is not possible due to the challenges in valuating protection of human lives and health. Therefore two main indicators are proposed: one assessing economic assets saved from destruction by climate change impacts (saved wealth) and one calculating human lives and health protected (saved health). The former indicator is a combination of two values, one of which is the absolute value of wealth saved, while the other looks at the relative wealth saved. This is done in order to better take into account vulnerability. The health indicator uses the concept of disability-adjusted life-years saved (DALYs).

The wealth indicator is calculated in a procedure that first estimates the expected wealth existing in the project area over time. Subsequently, the expected climate change damages during the lifetime of the adaptation project are calculated to set the baseline. A frequency distribution of damaging events is used for this purpose. Finally, the remaining damages after implementation or the project are assessed.

To reduce uncertainties that may make the indicator calculation irrelevant, coordinated approaches for the determination of wealth forecasts and damage frequency curves are required. A political agreement on the climate and economic models used would help. Here, the regulatory structure for the evaluation of emission mitigation projects in the context of the Clean Development Mechanism could serve as example. As an initial step, the indicator systems of adaptation funds should be oriented versus outcome indicators. Moreover, indicators should periodically assess the risk of maladaptation, especially for projects with a very long lifetime. The links between outcome and impact indicators should be studied in more detail.

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Web-GIS Tools for Climate Change Adaptation Planning in Cities

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Abstract

This chapter explores the state of the art in existing climate change risk, vulnerability, and adaptation assessment tools, with a focus on web-based tools. It then details the development and application of two online decision support tools created for climate change adaptation planning in cities – a Risk and Vulnerability Assessment Tool and Surface Temperature and Runoff (STAR) Tools. Both are freely available web-GIS tools that can be used to inform policy, strategy, and development. The Risk and Vulnerability Assessment Tool, developed through a collaborative and iterative process, follows the principles of an online public participation GIS. The Assessment Tool delivers GIS data and analysis functions online, widening the possibilities for participation in climate change adaptation planning. The STAR Tools enable assessment of the impacts of climate change on temperature and runoff in a specified urban area and evaluate the potential of green infrastructure as a climate change adaptation response. The STAR Tools can be used to develop "what if" scenarios, to illustrate how changes resulting from different land surface cover and climate change scenarios can impact upon local surface temperatures and runoff. The chapter presents the lessons learned from the development and application of these tools in municipalities across Europe and discusses key challenges for developing such tools to aid effective climate change adaptation planning in cities.

Keywords

Climate change adaptation • Urban areas • Climate resilience • Vulnerability • Risk assessment • PPGIS • Web-GIS

Introduction

Climate change, causing temperatures and sea levels to rise and an increase in the frequency and intensity of extreme events such as heat waves, droughts, heavy rainfall, and storm, presents risks to human and natural systems (IPCC 2014). The IPCC assessment reports confirm that climate change should be addressed by both mitigating the greenhouse gas emissions that are causing global warming and adapting societies to a new climate context to enhance resilience to current and future climate hazards (IPCC 2013, 2014). While mitigation actions have been acknowledged as essential for some time, adaptation has more recently emerged as a central area in climate change research, in country-level planning, and in the implementation of climate change strategies (IPCC 2014).

Since around 50 % of the world's population is now urban and with further growth anticipated within cities in developing countries, increasing concern is being raised about the potential impacts of climate change on urban environments and their growing populations and valuable assets. The assessment of climate change risk can help with improving the resilience of urban areas to present climate hazards in addition to providing information to guide adaptation strategies necessary for reducing future risks associated with climate change impacts.

Risk can be conceptualized through a framework comprising hazard, vulnerability, and exposure (Crichton 2001). Thus, the assessment of climate change risks can be undertaken through detailed understanding the three components – hazard, vulnerability, and exposure – where:

- Hazard is defined as the extent, severity, and probability of the climatic hazard of interest (such as a heat wave or flood event).
- Exposure refers to the degree to which elements at risk (such as people or infrastructure) may come into contact with the hazard of interest.
- Vulnerability is defined as the susceptibility to damage of the elements at risk (such as people or infrastructure) to a particular hazard at a particular intensity (as determined by the degree of exposure which could occur) (Lindley et al. 2006).

Risk assessment with the use of the hazard–exposure–vulnerability framework is useful because it enables consideration of the inherent vulnerability of elements at risk such as infrastructure or populations, rather than focusing on impacts only (Lindley et al. 2006). Identifying where vulnerability is high is central to targeting locations which require climate change adaptation strategies. Adaptation strategies act to reduce vulnerability by lowering exposure and increasing resilience of elements at risk to climate hazards. Thus, where vulnerability is reduced, the risk associated with impacts of climate hazards is significantly reduced (Lindley et al. 2006).

Appropriate data, knowledge, and information are vitally important to enable the assessment of climate change-related risks and a prerequisite to identifying city-scale adaptation responses. Spatial data and information in particular can provide the knowledge needed to identify context-specific vulnerability, thereby enabling spatially targeted assessments of risk and implementing appropriate adaptation responses across cities. A web-GIS (or Internet GIS) approach enables delivery of GIS data and analysis functions on the Web through the Internet (Peng 2001). Web-GIS tools therefore enable spatial information to be integrated and readily accessible to a wide range of stakeholders, creating a participatory environment and facilitating collaboration in climate change adaptation planning.

This chapter focuses on the development and application of two web-GIS tools to aid climate change adaptation planning, produced as part of the GRaBS Project (see section "The GRaBS Project"). A review of the state of the art in existing online vulnerability, risk, and climate adaptation decision tools was undertaken before the development of the GRaBS Tools began. This review is presented in section "Review of Online Tools for Climate Change Vulnerability, Risk, and Adaptation Assessment." Sections "The GRaBS Climate Change Risk and Vulnerability Assessment Tool" and "The Surface Temperature and Runoff (STAR)

Tools" discuss the development and application of the two GRaBS Tools created. Section "Conclusions: Lessons Learned and Key Challenges" concludes the chapter with a discussion of the lessons learned and key challenges for developing and implementing such tools for climate change adaptation planning in cities.

The GRaBS Project

The Green and Blue Space Adaptation for Urban Areas and Eco Towns (GRaBS) project (2008–2011) was a network of 14 leading pan-European organizations involved in integrating climate change adaptation into regional planning and development (Table 1). A key emphasis of the project was upon much needed exchange of knowledge and experience and the actual transfer of good practice on climate change adaptation strategies to local and regional authorities. The ten European municipalities involved represented a broad spectrum of authorities and climate change challenges, all with varying degrees of strategic policy and experience. These authorities were required to develop Adaptation Action Plans (AAPs) – documents to help guide adaptation decision-making within their organizations. The AAPs were informed by exchanges of knowledge and experience, together with evidence tools delivered by the research institutions to support policymaking, which included a database of case studies (Kazmierczak and Carter 2010) and online climate change risk and vulnerability assessment tools.

Table 1 GRaBS project partners

GRaBS project partner	Location of organization
Town and Country Planning Association (TCPA)[a]	London, UK
The University of Manchester[b]	Manchester, UK
London Borough of Sutton	Sutton, UK
North West Regional Development Agency and Community Forests Northwest	North West Region, UK
Southampton City Council	Southampton, UK
Provincial Government of Styria	Styria, Austria
Municipality of Kalamaria	Kalamaria, Greece
KU CORPI	Klaipeda, Lithuania
The Amsterdam City District of Nieuw-West	Amsterdam, Netherlands
Regional Environment Centre for Eastern Europe	Bratislava, Slovakia
Etnambiente SRL	Catania, Sicily, Italy
University of Catania	Catania, Sicily, Italy
Province of Genoa	Genoa, Italy
City of Malmö	Malmö, Sweden

[a]Lead partner, with central management, communication, and administrative responsibility
[b]Responsible for developing the Assessment Tool, STAR Tools, and a database of case studies

Review of Online Tools for Climate Change Vulnerability, Risk, and Adaptation Assessment

Prior to designing a web-based GIS tool for urban climate change adaptation assessment, a review was undertaken in 2009 to explore existing vulnerability, risk, and adaptation assessment tools. This review has been updated here to include some more recent examples of tools. A "tool" was interpreted as anything which identified itself as such within the broad climate and adaptation field, found through literature search terms and selected online search engines. Although tools are emerging which attempt to integrate mitigation and adaptation goals, tools focused on mitigation tend not to include strong adaptation elements.

There are widely different views on what constitutes a tool for vulnerability and risk assessment and for risk management in relation to climate adaptation. Certain key criteria used in past reviews were applied here in order to ensure that similar tools were assessed. A review conducted for the United Nations Framework Convention on Climate Change (UNFCCC) refined the definition of an adaptation decision tool, specifying that it must have a clear user dimension and the possibility for users to be assisted in the process of evaluating options (Stratus Consulting Inc 1999). In particular it required tools to be able to link adaptation options to impacts and allow an assessment of trade-offs. Tools were also required to have a clear user group, have available documentation, and be applicable at the national, regional, or local scale (Stratus Consulting Inc 1999). While this is a useful definition of an adaptation decision tool, it is also very specific and, subsequently, may be restrictive. For example, applying this definition may exclude some of the useful models or methods subsequently developed, such as the UKCIP Adaptation Wizard (UKCIP 2008). More recent reviews such as Scholze and Wahl (2009) and Garg et al. (2007) apply broader criteria and definitions to adaptation decision tools, allowing inclusion of the most recent developments in adaptation decision tools. For example, Garg et al. (2007) considered tools which tackle both risk and adaptation themes in keeping with the IPCC's definition of vulnerability: "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2007, p. 883).

Garg et al. (2007) analyzed the specific aims and requirements of climate change-related decision support tools for the US Global Change Research Program. The analysis revealed that three core elements were required, as follows:

- Climate change policy development should be supported by providing mechanisms through which methods can be evaluated (such as scenario evaluations, integrated analyses, and alternative analytical approaches). These methods should be demonstrated using case studies.
- Successful climate change adaptive management and planning requires the development of information and other resources. Resources need to be clearly transferred from a research-based environment to an operational environment.

- Assistance is required to help stakeholders prepare appropriate scientific assessments and summaries of information to be used within the decision-making process and as a means to inform other relevant stakeholders as well as the media and the general public. In this context, the IPCC (2007) Fourth Assessment Report indicates that assessments need to be consistent, comparable, and transparent, allow integration, and represent reality as accurately as possible.

Given the huge variation in types of tools which could now be considered a form of climate change vulnerability and risk assessment tool, this review attempts a broad categorization of tools and provides indicative examples of each. Tools can be grouped into five key types. A brief introduction to each of these types is presented below, together with a number of exemplars of each type. It is notable that some tools may cut across one or more of these groups (Garg et al. 2007). Integrated Assessment Models are designed to look at a range of impacts and feedbacks in related sectors. However, no models directly dealing with urban climate risk and adaptation themes were found during the research for this review.

The five key groups of tools are as follows:

1. Risk and adaptation decision-making frameworks (process orientated): These tools are guidelines to completing risk assessments for the purposes of risk management: they do not actually provide the means to conduct risk assessments themselves. These tools guide users through the decision-making framework by using the questions that decision-makers would want to have answered as prompts and provide links to other sources to assist with collecting data to answer questions. Examples include the UKCIP Adaptation Wizard and UKCIP Risk Framework, Climate-ADAPT Adaptation Support Tool, and the Quality Standards for the Integration of Adaptation to Climate Change into Development Programming (CCA QS, UNDP's structural framework) (Table 2). Although many of these frameworks are generic and valid for all climate-related risks, some are specific to a single-risk theme and provide guidance and examples pertinent to that theme only.
2. Portals or "platforms": These provide a gateway to direct users to a set of more specific tools where information and/or guidance for risk and adaptation decision-making can be obtained. Some include the functionality to support limited manipulation or visualization of data from other sources. In general, they do not enable the creation of new data in response to specific user inputs. Examples include the World Bank Climate Change Data Portal and weADAPT (Table 2). The World Bank Portal includes additional tools for visualizing climate data, specifically the Climate Mapper (also a tool in its own right due to not being fully integrated within the host website). Other portals are much more independent from the tools to which they link, as is the case with the Adaptation Learning Mechanism (ALM) as the tools here are provided as links in a separate resource area.
3. General vulnerability, risk, or impact assessment techniques and approaches which can be applied to climate change risk and adaptation assessment: These

Table 2 Examples of climate change vulnerability, risk, and adaptation assessment tools

Name/type of tool	Purpose	Web link
Risk and adaptation decision-making frameworks (process orientated)		
UKCIP Adaptation Wizard	A guided five-step process to aid organizations to assess their vulnerability to climate change and aid adaptation planning	http://www.ukcip.org.uk/wizard/
UKCIP Risk Framework	A process based on standard decision-making and risk principles to identify risks, adaptation options and make decisions	http://www.ukcip.org.uk/wizard/about-the-wizard/ukcip-risk-framework/
Quality Standards for the Integration of Adaptation to Climate Change into Development Programming (CCA QS)	A framework for best practices to facilitate successful incorporation of climate change adaptation concerns in development projects	https://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5467.php
Adaptation support tool from Climate-ADAPT	Assists users in developing climate change adaptation policies by providing guidance and links to relevant sources and tools. Based on the UKCIP Adaptation Wizard and other risk assessment frameworks	http://climate-adapt.eea.europa.eu/web/guest/adaptation-support-tool/
Portals or platforms		
World Bank Climate Change Data Portal	"One stop shop" for climate-related data and tools. Produces map output, online summaries and links to additional tools	http://www.worldbank.org/climateportal
weADAPT	Portal to a range of tools for assisting climate change adaptation	http://www.weadapt.org/
Climate Mapper	Maps and visualizes climate model data for onward use by a wider user community to improve vulnerability assessments	http://www.iagt.org/focusareas/envmon/climatechg.aspx
Adaptation Learning Mechanism (ALM)	A knowledge-sharing platform providing an information database of resources on adaptation knowledge	http://www.adaptationlearning.net/
Climate-ADAPT	The European Climate Adaptation Platform is a portal to a large amount of information and includes tools such as the adaptation support tool, case study search and map viewer	http://climate-adapt.eea.europa.eu/

(*continued*)

Table 2 (continued)

Name/type of tool	Purpose	Web link
General vulnerability, risk, or impact assessment techniques		
Social Vulnerability Index for the USA	A comparative metric that facilitates the examination of geographic variation in social vulnerability and an indicator of disaster recovery	http://webra.cas.sc.edu/hvri/products/sovi_32.aspx
Severe Weather Impacts Monitoring System (SWIMS)	Online data capture tool enabling users to record impacts and responses to assess vulnerability to severe weather events	http://www.kent.gov.uk/business/Business-and-the-environment/severe-weather-impacts-monitoring-system-swims
High-level or screening models		
Climate Wizard	Shows historical and future climate projections for technical and nontechnical audiences and enables spatial data download	http://www.climatewizard.org/
MIST (Mitigation Impact Screening Tool)	Determines potential impacts of different Urban Heat Island (UHI) mitigation strategies on average temperatures	http://www.heatislandmitigationtool.com
Detailed models		
PRECIS (Providing Regional Climates for Impacts Studies)	Enables experimentation with The Hadley regional climate modeling system, including various data output options	http://precis.metoffice.com/index.html
AUSSSM	A numerical model that simulates the urban microclimate and enables analysis of the impact of changes in design parameters on the urban heat island effect	http://ktlabo.cm.kyushu-u.ac.jp/e/UHI/ausssm_tool/ausssm_top_e.htm
ENVI-met	Stand-alone fine-scale model which allows the impacts of different types of urban greening on buildings to be quantified	http://www.envi-met.com/

are more generic methods, including cost–benefit analysis, expert judgment, and scenario analysis (Willows and Connell 2003; Stratus Consulting Inc 1999). Additional tools useful to spatial planners include identifying constraint (or sieve mapping), tipping points/threshold analysis, high-level risk assessments, and decision pathway tools (ESPACE 2008). For vulnerability assessment a range of indicators, methods, and datasets have been produced, for example, the Social Vulnerability Index for the USA (SoVI). Individual computer-based tools usually incorporate one or more of these approaches, e.g., cost–benefit in addition to other assessment elements.

4. High-level or screening models where new data are created based on input datasets from one or more offline models: These would usually provide functionality to allow data to be manipulated and analyzed to provide new information which may be in real time. Examples include the Climate Wizard (Table 2). Given the challenges for hosting very complex tools on the Internet, online tools are usually of this form rather than very detailed models. These high-level models tend to be at national or regional level, with data at relatively coarse scale. Examples include the MIST tool (Table 2). There are few screening tools available below city scale.
5. Detailed models (usually for individual risk themes or sectors) which require considerable data and resource input and often a high level of technical competence: Such sophisticated models take a long time to run and are therefore less suited to online deployment, though they may run on intranet sites. An example is the Met Office PRECIS tool, a scaled-down climate model which takes days or months to process simulations. These tools have an important role to play, since once processing has completed offline, data outputs can be integrated into high-level models or portals. The AUSSSM and ENVI-met are detailed models for understanding urban heat island mitigation options.

Recommendations for a New Climate Adaptation Decision-Making Tool

Scholze and Wahl (2009) analyzed the Strengths, Weaknesses, Opportunities, and Threats (SWOT) of existing adaptation decision-making tools (Table 3), which are particularly valuable to reflect upon before developing a new tool, both to establish technical and functional requirements and to assist with developing the general "look and feel" of the tool. The opportunities highlighted in Table 3, including awareness raising, stakeholder interest to use and apply, customization to local settings, and developing a toolbox of all tools, are useful ideas to progress. Identified threats to be avoided include the challenge of making tools sufficiently reliable yet easy to use for a wide audience. Further, while online tools enhance access to evidence to support climate change adaptation and decision-making, a key weakness identified is the dependence on good Internet connectivity. Internet connection speeds and coverage have greatly improved in the last 20 years. However, detailed climate change information may by necessity be data intensive, and therefore models over the Internet may be prone to slow down.

Drawing upon this SWOT analysis, recommendations for new tools include to place the tool within a clear risk management and adaptation assessment framework/process, to house the tool within a website which acts as a data/tool portal, to ensure that terminology is clear and full documentation is provided for users, to ensure that the functions include those provided in existing tools, and to consider the possibility of a data upload element in the tool.

Table 3 Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of adaptation decision-making tools (after Scholze and Wahl 2009)

Strengths	Weaknesses
Capacity-building elements	Lack of tools designed for the national level
Improved access to climate change information	Lack of consideration of cross-sectoral interactions
Evidence of entrepreneurial spirit in the tool developer community	Lack of consideration of financial implications (e.g., cost–benefit analysis)
Good handling of physical aspects very well (but are not as good on socioeconomic factors)	Lack of linkage to disaster risk management
Provision of data for nonexperts in an easy to understand format	Lack of communication of limits and constraints
Free, simple to use and open-source tools	Tools are not always developed with partners and can be donor-centric
Assistance with open and transparent decision-making process	Lack of monitoring and evaluation
Assistance with decision-making process	Tools do not handle implementation issues
Richness in the diversity of tools serving different needs; all are useful in some way	Online tools depend on good Internet connectivity
	Need more engagement with soft solutions
Opportunities	Threats
Customization to local settings	Resources could be wasted if there is too much overlap and poor coordination
Stakeholder interest to use and apply tools	Oversimplistic tools
Creation of a toolbox of all tools	Overshadowing of existing tools and policies and creation of “climate bias”
Cataloging all tools to see whether new tools are necessary to fill gaps	Competing tools
Greater coordination/collaboration needed	
Creation of high-quality tools through links to research and the scientific community	
Awareness raising (public and data needs)	
Business opportunities	
Development of peer review mechanisms	
Including adaptation and mitigation	
Capturing of local knowledge	
Handling trade-offs	
Identification of tools useful in particular settings and for particular tasks	
Integration of disaster risk management ideas to ensure valuable knowledge not missed	
Data quantity/quality transparency and assessment	

This review identified that there was no existing tool specifically for vulnerability assessment and that there was scarcity of tools specifically focused on cities and associated themes of interest. Furthermore, the use of a web-GIS approach is an accepted format for the development of tools in climate change adaptation planning. A web-GIS (or Internet GIS) approach enables delivery of GIS data and analysis functions on the Web through the Internet (Peng 2001). Spatial representations are important in the planning process, and web-GIS can enhance the traditional planning process through its interactive map exploration features (Dragicevic and Balram 2004). Dragicevic (2004) identifies three main ways that web-based GIS has enhanced the open use of GIS: spatial data access and dissemination; spatial data exploration and geovisualization; and, spatial data processing, analysis, and modeling. Web-GIS can effectively support the task of integrating data from disparate sources, making these available through the whole planning process, thereby enabling open and transparent decision-making (Dragicevic and Balram 2004).

The GRaBS Climate Change Risk and Vulnerability Assessment Tool

The GRaBS Climate Change Risk and Vulnerability Assessment Tool (hereafter, Assessment Tool) follows the principles of an online Public Participation GIS (Kingston et al 2000; Kingston 2007). The main aim was to develop web-based Geographical Information Systems (GIS) to enhance public involvement and participation in environmental planning and decision-making. These systems are referred to as PPGIS and are a form of Planning Support System. The main objective is based on the belief that by providing all stakeholders, including citizens, with access to information and data in the form of maps and visualizations, they can make better informed decisions about the natural and built environment around them.

Development of the GRaBS Assessment Tool

Development of the Assessment Tool followed an explicit methodology (Fig. 1). Following the review of existing state-of-the-art risk and adaptation tools, the project team embarked on a collaborative process of tool development with all the GRaBS partners (Table 1), in order to shape the exact form and function of the final Assessment Tool (Fig. 1). This process involved using Checkland's (1999) soft systems methodology to inform system development. Firstly, a user needs and requirements analysis of all partners was carried out via an online questionnaire to inform the writing of the functional specification which fed into the building of the beta version of the tools. This was piloted at a user workshop to test functionality and usability. Feedback from this workshop then led to numerous refinements to the

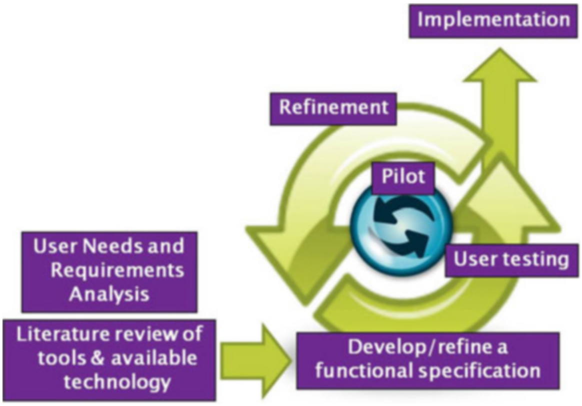

Fig. 1 The GRaBS Risk and Vulnerability Assessment Tool development process (Cavan and Kingston 2012)

tool followed by further user testing and refinement before the tools were fully deployed. This process is reported in detail in Cavan and Kingston (2012).

The nature of the GRaBS project with a pan-European user-base meant that the tool had to be built using a common map base for all partners. Using Google Maps' Application Programming Interface (API) which is free, generic, highly customizable, and probably, most importantly from a user perspective, very simple to use and navigate, meant that a single generic tool could be built for all partners. The GIS data is served over the top of Google Maps using MapServer, which converts proprietary spatial GIS data into an image format (in this case png) which speeds up the map rendering process for the user. This also means that the user of the Assessment Tool does not have access to the source GIS data, overcoming data access restrictions which might apply to some of the datasets depending upon their source of origin. The tool can therefore be categorized as a high-level or screening tool because the data used in the model is processed offline and the tool does not involve real-time processing of models (Scholze and Wahl 2009).

The Assessment Tool adopts a spatial screening risk assessment framework (Lindley et al. 2006, 2007), whereby an explicit set of spatial data layers are created in order to represent each component of risk (including separate layers representing hazard, vulnerability, and exposure). GIS overlay is used to represent the spatial coincidence that would be required in order for risk to be realized at a particular location. Thus, the online Assessment Tool presents climate change risks and vulnerabilities at a range of spatial scales from EU-wide to the neighborhood. The Assessment Tool allows decision-makers to overlay different raster, point, and polygon data layers to visually assess their spatial relationships and examine appropriate attribute information (Fig. 2b). For example, the user can investigate the spatial incidence of flood hazard, together with the distribution of vulnerable people, social and critical infrastructure.

There are over 350 different spatial layers in the Assessment Tool, with 32 EU-wide layers, and individual partner level data ranging from 7 to over 60 layers. This includes geospatial data from the following categories:

a

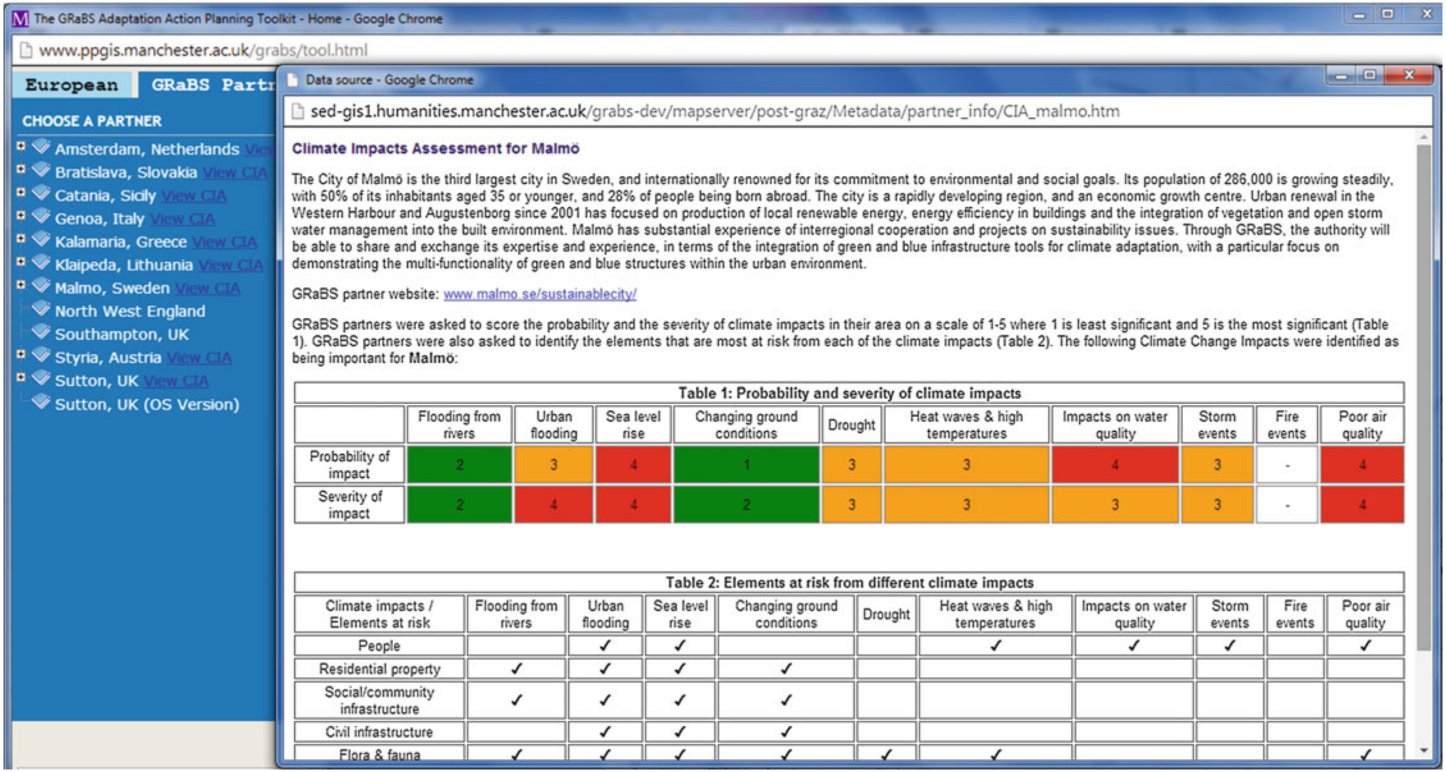

Fig. 2 (continued)

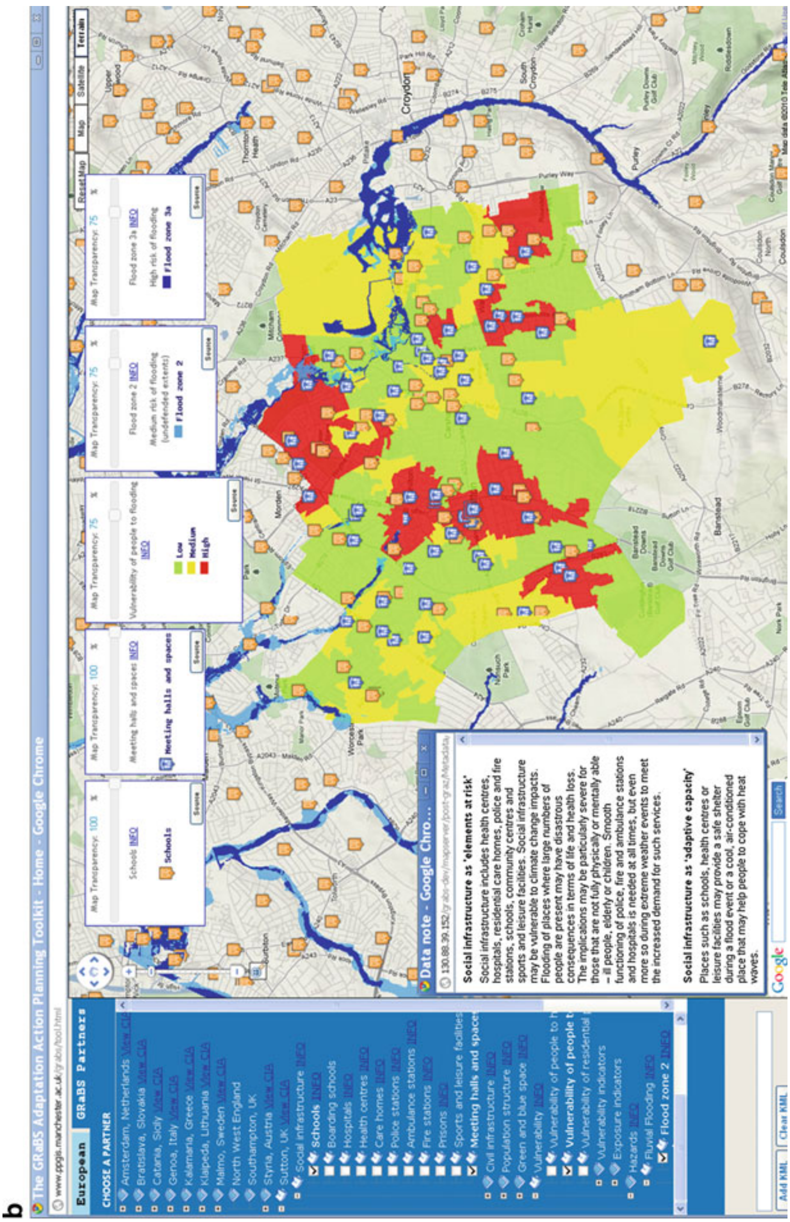

Fig. 2 The Risk and Vulnerability Assessment Tool: partner level interface (**a**) Climate Impacts Assessment and (**b**) vulnerability map

- Green and blue space, e.g., parks, public open space, rivers, canals, and lakes
- Vulnerability indicator, e.g., people aged over 75 years, people living on a low income
- Social infrastructure, e.g., schools, hospitals, fire stations, and public buildings
- Civil infrastructure, e.g., power stations, water treatment works, and railway stations
- Hazard, e.g. river, surface water, and sewer flood risk areas
- Vulnerability index, e.g., people vulnerable to flooding and high temperatures
- Population structure, e.g., population density and deprivation
- Urban development, e.g., building types and residential areas

The variability in the amount of local level data reflects both the extent to which different municipalities have been collecting relevant geospatial data and their ability to work across departmental boundaries to obtain necessary information. Additionally, qualitative information provided in hundreds of *data notes* offers important background information on the issues of climate change, vulnerability, and adaptation, including an explanation of key terms and why each layer may be important to consider in climate change adaptation planning. A summary of the key elements and functions of the Assessment Tool is provided in Fig. 3.

ELEMENTS	EXPLANATION
Portal	The tool is housed in a website which acts as a portal and provides other tools and guidance for risk and adaptation decision-making
Risk management framework	The tool is structured around a risk framework, including the themes of vulnerability, hazard, exposure, risk and elements at risk
EU and case study levels	The tool has two levels of operation – European and case study level, which includes the GRaBS project partners' study areas
Climate impact assessment (case study level only)	A pop-out window provides an assessment of the climate hazards and elements at risk of key importance within the GRaBS partners' area
FUNCTIONS	
Visualisation	Real-time display of point, polygon and raster geospatial data layers
Overlay	Overlay of up to five geospatial data layers
Transparency	A slider bar enables the user to adjust the transparency of the colour of a theme to enable the base map to be viewed more easily or to enhance the overlay function
Zoom, pan	Map navigation functions
Data note	Pop-up window providing clear terminology and interpretation of the data
Data source	Pop-up window providing metadata information
Data query	Enables querying of the attribute information of the geospatial data
Add kml	Enables upload of local data - particularly useful for sensitive or restricted information
Basemap	The user can view satellite, terrain or map modes

Fig. 3 Key elements and functions of the Risk and Vulnerability Assessment Tool (Cavan and Kingston 2012)

User guidance included the creation of three storylines or use cases (Cockburn 2000), which offer typical examples of how an individual or organization might use the Assessment Tool to support climate change adaptation policy and decision-making within their organization.

Application of the Risk and Vulnerability Assessment Tool Across Europe

Adaptation Action Plans (AAPs) were the key output of the GRaBS project from 11 of the partners – the municipal or regional planning authorities and partners that provide a planning support function. The AAPs were developed via a six-stage cyclical process, as follows:

1. Baseline review and process launch
2. Raise awareness and explore adaptation responses
3. Agree high-level aim and objectives
4. Agree delivery program
5. Implementation and monitoring
6. Evaluation and reporting

The AAPs represent a potentially significant influence over adaptation issues in the areas that they cover and support the partner urban areas and regions in developing responses to climate change and extreme weather. The key role of the Assessment Tool in supporting the GRaBS AAPs was identified through better understanding the connections between the Assessment Tool and three interlinked issues – the objectives of AAP development, the stages of AAP development, and the generic barriers constraining effective adaptation (Carter et al. 2010; Fig. 4). Taking these issues collectively, the Assessment Tool was identified as able to support adaptation planning and decision-making in four key areas: (1) raising awareness of climate change impacts and adaptation responses, (2) encouraging participation in adaptation planning, (3) enhancing data availability and use, and (4) supporting decision-making.

A questionnaire sent to GRaBS partners (Table 1) in January 2011 allowed an evaluation of how the Assessment Tool had been applied, the identification of lessons learned, and suggestions for future development. The following sections present an analysis of this information in the context of the key areas identified above.

Raising Awareness of Climate Change Impacts and Adaptation Responses

Raising awareness of climate change is an important early stage in the process of developing adaptation responses and can help to improve the adaptive capacity of individuals and stakeholders who have an important role in responding to associated impacts (Carter et al. 2010).

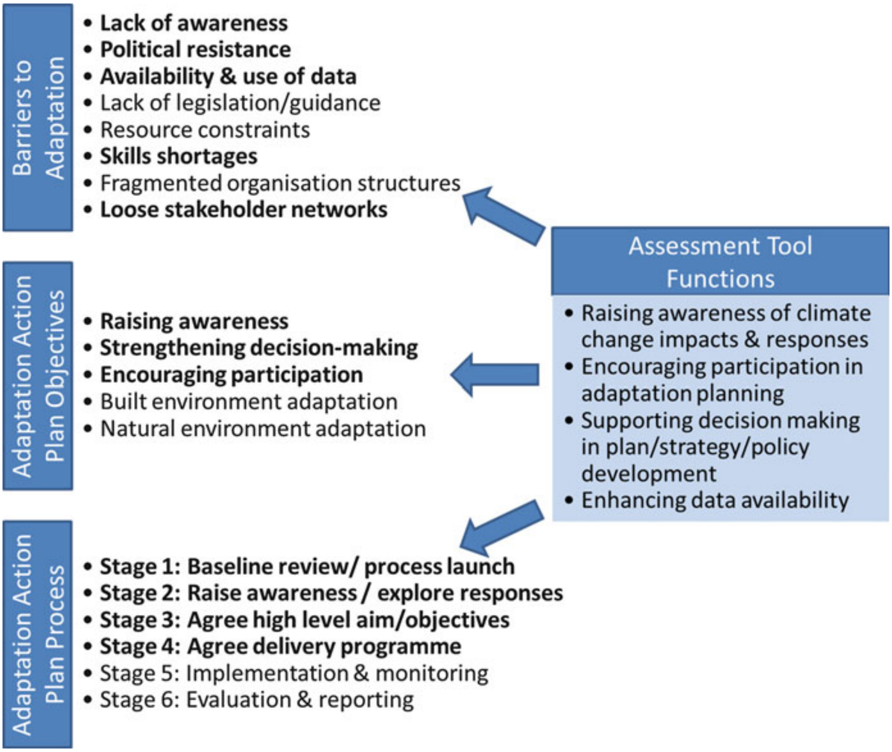

Fig. 4 The role of the Risk and Vulnerability Assessment Tool in supporting the GRaBS Adaptation Action Plans (After Carter et al. 2010)

The Assessment Tool was an excellent means of raising awareness of climate hazards and vulnerability among the public and decision-makers and a way to visualize "what can happen and what we need to take action on" (Cavan and Kingston 2012, p. 265). The Assessment Tool was demonstrated at many awareness raising events held for both internal and external stakeholders focused upon climate change impacts and local adaptation responses. A common structure to these events involved providing an introduction to climate change adaptation issues, the GRaBS project and Assessment Tool, a live demonstration of the Assessment Tool, and/or hands-on workshop session, questions, and discussion. The feedback from workshops was positive, with an emphasis on its user-friendly interface and useful spatial and contextual information provided in data notes.

It was noted that specific discussion at awareness-raising events depended upon the audience. When the Assessment Tool was presented to the public or private sector stakeholders with greater adaptation expertise, discussions often stimulated more questions than answers, for example:

- Regarding the capability (or limitations) of the Assessment Tool
- How to plan for future scenarios

- Its transferability to local authorities beyond the GRaBS partnership and the accessibility of relevant data
- Its principle use for awareness raising among local councilors or communities
- Conflicts with existing GIS tools in terms of building an evidence base for planning

Encouraging Participation in Adaptation Planning

Developing adaptation responses in urban areas is complex due to the ubiquitous nature of climate change impacts occurring across different sectors and spatial scales. Bringing stakeholders together in stakeholder workshops and community events can facilitate establishment of collaborative networks and generate consensus and a shared vision toward adaptation issues and responses, which will enhance the effectiveness of the AAP implementation process.

The Assessment Tool was valuable in encouraging participation in adaptation planning at stakeholder workshops and community events. For example, the London Borough of Sutton held a stakeholder workshop which incorporated a practical computer session for around 35 participants, including representatives of statutory bodies such as the Environment Agency, Natural England, and utilities (e.g., Thames Water), in addition to officers from a range of local authority departments. After an introduction to the GRaBS project, a hands-on workshop session enabled participants to explore the Assessment Tool. The discussion and feedback sessions were particularly valuable for the development of Sutton's "Community Map" (see section "Enhancing Data Availability and Use").

The Northwest England partner (NWDA and Community Forest Northwest) connected the Assessment Tool to other resources and tools aimed at encouraging participation in adaptation planning. The Community Forest Northwest website "Green Infrastructure to Combat Climate Change"[1] includes a wealth of resources developed through the GRaBS project including action guidance, an evidence base, an evidence report, and a link to the Assessment Tool. Specifically, the Community Forest Northwest encouraged stakeholders and community groups to apply the Assessment Tool through two key mechanisms:

- The "Framework for Action" – an action guidance document that can be used to aid issues concerning policy development and delivery.
- "Community Adaptation Training" – whereby the Assessment Tool is provided as one activity for community groups in the training materials. The training is intended for use by professionals with community groups to engage them on the need for climate change adaptation and/or how their local green infrastructure helps to adapt their neighborhood to climate change.

[1]Green Infrastructure to Combat Climate Change:http://www.greeninfrastructurenw.co.uk/climatechange/

Enhancing Data Availability and Use

Data availability was highlighted as a key barrier to climate change adaptation planning. The process of developing the Assessment Tool raised significant issues regarding data accessibility and availability within planning authorities, which need addressing if adaptation action is to be delivered successfully. A key function of the Assessment Tool is that it required the collation of spatial data in a consistent format to support adaptation planning. For the Municipality of Kalamaria, a lack of access to relevant data in relation to climate change vulnerability was a pertinent issue, and the AT's role also included identification of the gaps in necessary data:

> Awareness raising may be the most important use. The general lack of data on our behalf grabbed the attention of the attendees… Vulnerabilities have not been recorded for the climate change impacts at a local level in Greece so there is a need for them for proper estimation of risk.

Using a consistent framework throughout the Assessment Tool added significant value and allowed partners to investigate each other's local datasets, to assist in the development of their own tool. For example, the Amsterdam City District of Nieuw-West revealed that:

> We used other partner tools to demonstrate that there are still crucial data layers missing in our tool. By showing the value of these layers we hope that in the future, we can still gather these data and add them to the tool.

The Assessment Tool development process required the collation of data across different departments, thereby facilitating cross-departmental working and awareness raising among local authority staff. A key finding of the project was the need to break down silos between departments in order to gather evidence on the need to act on adaptation and to support adaptation planning.

The development of the Assessment Tool also stimulated GRaBS partners to develop local online GIS tools and portals. This includes the Province of Genoa's ADAPTO Adaptation Action Planning Toolkit, which enables visualization of local indicators for the assessment of the vulnerability of environmental parameters (Provincia di Genova 2013). In addition, the London Borough of Sutton developed their own web-GIS to facilitate community engagement and feedback on climate change and flooding issues at the neighborhood scale. The London Borough of Sutton (2013) online "Community Map" incorporates a comprehensive range of environmental issues relating to the delivery of council services, in addition to adopting the conceptual risk framework and relevant geospatial information from the Assessment Tool.

Supporting Decision-Making

The Assessment Tool supported decision-making in three ways: within Adaptation Action Plans, internal strategies, and through guidance documentation. The role of the Assessment Tool in the GRaBS AAP process differed between partners according to the form and function of the AAP, the stage of the AAP process that the Assessment Tool was applied, and the local information available to each partner (Carter et al. 2010). Thus, the application of the Assessment Tool within

AAPs also differed between partners, which ranged from explicit inclusion in high-level policy statements and delivery programs to use for gathering material to inform the development of the AAP, e.g., through analysis of the spatial data, to stakeholder workshops and meetings. Within the time frame of the GRaBS project, the Assessment Tool was applied at the first two stages of the AAP process by all of the GRaBS partners responsible for producing AAPs, where stage 1 is a baseline review and process launch and stage 2 is raise awareness and explore adaptation responses (Fig. 4).

Additionally, the Province of Genoa, Southampton City Council, and London Borough of Sutton incorporated the Assessment Tool into stages 4 and 5 (agree high-level aim and objectives and agree delivery program; Fig. 4). For example, Action 4 of the Province of Genoa's high-level policy statement states that

> Vulnerability to climate change risks, and adaption measures should be evaluated through a reliable, updated and flexible tool, able to answer specific local issues; then, the GRaBS assessment tool should be used both for building programmes and Provincial level, both for delivering green and blue infrastructure projects in homogenous physical contexts. (Provincia di Genova 2011)

Priority 4 of Southampton City Council's AAP "we will minimise the impact from flooding for the city" stated that it should implement the Assessment Tool in the Council's delivery program (Fig. 5). Additionally, Southampton City Council applied the Assessment Tool in internal strategies, specifically, strategic decision-making for climate change adaptation planning:

> It has been used internally by officers, already familiar with climate related risks, to help inform strategy work that is currently underway. In particular, it has been used to test the validity of assumptions about areas of the city that were believed to experience problems.

Suggestions for Future Tool Development

The final part of the questionnaire aimed to gather comments about future tool development, specifically, if there was a future version of the tool, what would users want it to do? Many of the GRaBS partners expressed the desire for the Assessment Tool to include future modeling scenarios, e.g., for land use, development, and climate, over various time horizons, including the "possibility to show a "before and after" situation about climate change adaptation effects in the region," and "the tool should also include the information on vulnerable objects (not only existing ones, but also planned developments)." The flexible spatial screening risk assessment framework adopted does allow assessing scenarios of different adaptation options, by adding new layers representing each component of risk according to potential future changes. However, such scenario development requires significant scientific research to be conducted at case study level before such spatial data layers can be included. The Assessment Tool therefore can at present only deal with current vulnerability to climate change. The Surface Temperature and Runoff (STAR) Tools were later developed to address this limitation and provide some modeling capabilities, which is the focus of the next section.

4. We will minimise the impact from flooding for the city
Southampton will be a city that is resilient to all but the most extreme floods and has robust emergency plans to respond to, and recover from, flooding.

Ref	Aim	Action	Measure of Success	Timescale	Progress	Lead	Resources
4.3	Raise individual and community level awareness of flooding and the measures they can undertake to reduce risks to become more 'adaptation aware' and able to manage the consequences of flooding	CCATCH project implementation of engagement strategies in Hampshire 2012-13	To be confirmed	2013	Amber	Rob Crighton, Special Projects Team Leader, Planning and Sustainability	✓
4.5	Market the key development assets in the city and reassure investors that Southampton is a safe place to invest	Develop an urban design showcase in partnership with the EA and the University which demonstrates managed adaptive approach to flooding in the city attracting prospective developers	A suitable site in Southampton is identified by 2011	2011	Green	Kay Brown, City Design Manager, Corporate Policy and Economic Development	✓
			Number of stakeholders signed up to attend the event	2013	Green		✓
4.6	Reduce flood risk to the city's most critical assets and vulnerable communities	Identify and map existing vulnerabilities to flooding and climate impacts in terms of the potentially adverse health and other consequences on people, property and essential infrastructure, taking critical thresholds and the extent of resilience into account	Climate Change Risks and Vulnerabilities Assessment Tool finalised and implemented through the city council emergency planning unit	2011	Amber	Sustainability Team and Emergency Planning Unit	✓

Fig. 5 Southampton City Council's Low Carbon City Strategy 2011–2020. A section of the delivery program for priority 4 (Southampton City Council 2011)

The Surface Temperature and Runoff (STAR) Tools

There is an increasing body of literature that emphasizes the multifunctional benefits of green infrastructure and its important role in adapting urban areas to climate change through, for example, flood alleviation and temperature regulation (Gill et al. 2007; Bowler et al. 2010). However, it is important to be able to quantify such benefits in order to illustrate the importance of green infrastructure and to highlight how changes to the built environment at a local level can affect the delivery of important ecosystem services it provides.

The STAR Tools is an online toolkit that enables users to assess the potential of green infrastructure in adapting urban areas to climate change (Fig. 6a). It includes two modeling tools – a Surface Temperature (ST) and a Surface Runoff (SR) Tool – both of which are underpinned by scientific models (see Gill 2006 for full details):

- Surface Temperature Tool: developed from an urban climate model (Tso et al. 1990, 1991; Whitford et al. 2001) and produces outputs of maximum surface temperature expected during the two hottest days in summer for a specified study area (98th percentile). Since the mix of different land surfaces (such as proportion of green cover, water, and buildings) is an important determinant of the land surface temperature, these parameters are also accounted for in the model.
- Surface Runoff Tool: based upon the US Soil Conservation Service approach (SCS 1972), this tool outputs the percentage of the rainfall that becomes surface runoff and the volume of the surface runoff for a given amount of daily rainfall. The Surface Runoff Tool thus calculates how much rainfall from a given event will not be converted to surface runoff; this could be because this rainfall is intercepted (e.g., by plants and vegetation), infiltrated (e.g., into the soil), or stored (e.g., on surfaces). The remaining rainfall is converted to surface runoff. Again, the land surface cover type is an important determinant of rainfall runoff and is accounted for in the model, as is soil type.

The STAR Tools are applicable for the “neighborhood” scale (recommended between 0.4 ha and 4 km^2), though they can be run for more than one neighborhood or study area at a time. The STAR Tools have few input requirements and are straightforward to use. The key benefit of the STAR Tools is that they allow the role of urban vegetation to be explored. This is possible through creating “what if” scenarios for both climate and land surface cover, for example, running the STAR Tools with the “business as usual” or current climate and land surface cover, compared to adding 10 % green cover and comparing the resulting output surface temperature or runoff. If several neighborhoods are run, the results can be mapped using GIS (see section Application of the STAR Tools to inform the Mersey Forest Plan), although this functionality is not available in the tool itself.

The STAR Tools enable assessment of how surface temperatures and runoff may vary under future climate projections and as the proportion of green space is increased or decreased. Thus, it can help to answer important questions such as: given the changing climate, how much greening do we need in particular areas to

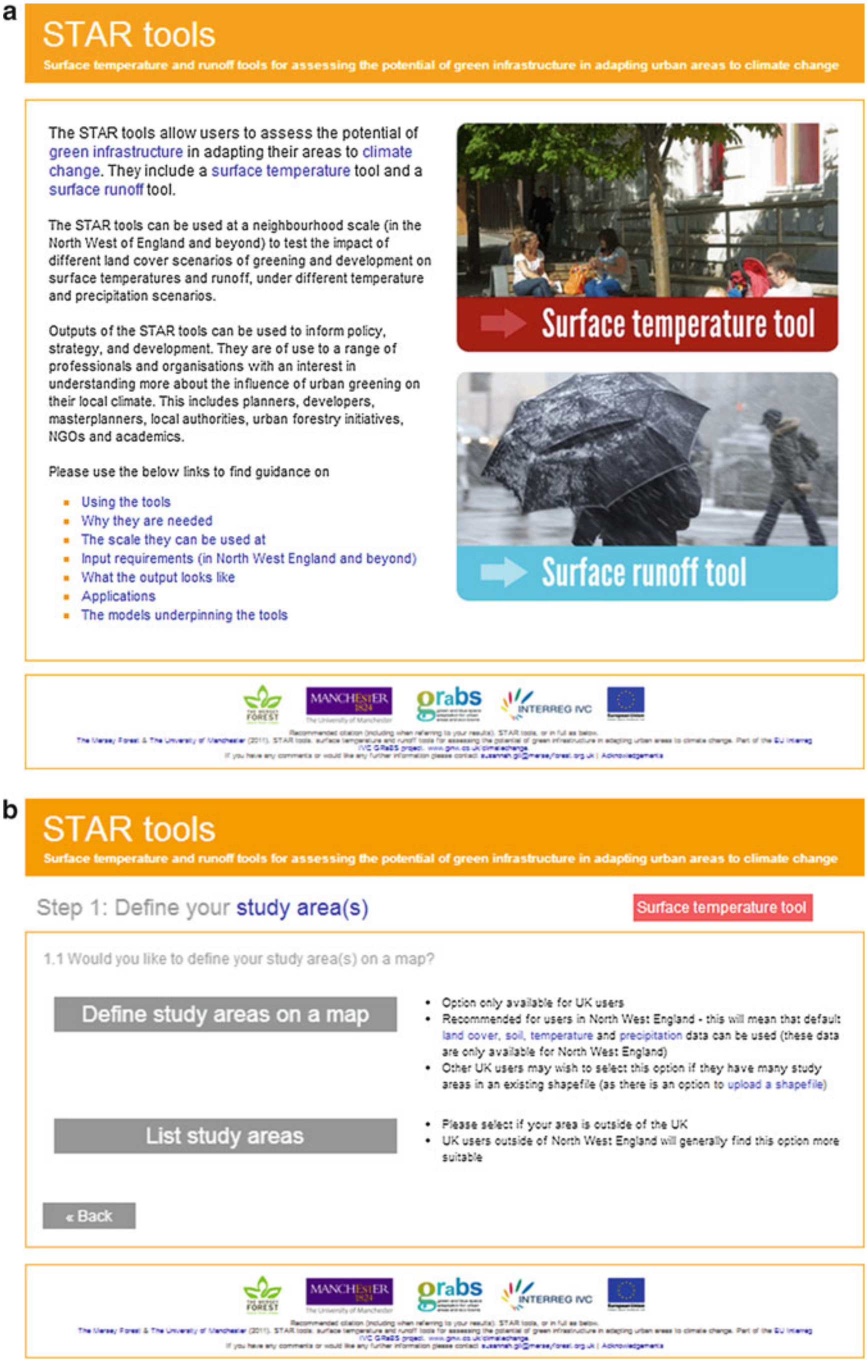

Fig. 6 The STAR Tools interface, (**a**) homepage, (**b**) defining a case study area, http://maps.merseyforest.org.uk/grabs/

achieve certain reductions in temperatures or runoff in the future? What impact would a proposed development have upon temperature or runoff at the neighborhood scale? Such information could also be used to set targets for green infrastructure provision within new developments or in existing neighborhoods. In this way, the information could be used to guide policy and strategy development – both urban development and green infrastructure policies. The outputs of the STAR Tools are thus potentially of use to a range of professionals including planners, developers, master planners, local authority officers, NGOs, urban forestry initiatives, and academics.

Developing the STAR Tools

The STAR Tools were developed as an addition to the Assessment Tool, in response to feedback regarding the desire to project future land use scenarios and their potential impact. While the development of the STAR Tools was focused upon North West England (one of the GRaBS case study locations), it was important that users outside of this area could also apply the STAR Tools to investigate the potential of green infrastructure in adapting their specific urban neighborhood to climate change. Therefore, users enter the Tools in two ways (Fig. 6b). If the study area is located in the UK, users can define their study area(s) on an interactive map, driven by OpenLayers and Ordnance Survey's OpenSpace. All default input values are automatically provided for the Mersey Belt within North West England, including climate projections, land surface cover, and soil data, together with detailed information about data sources and model assumptions. Users also have the option to simply list their study areas. At the next stage, the user is then able to both insert their own input values (including climate projections, land surface cover, and soils) and modify the default model parameter values (set to North West England climate and environment context) to adapt the STAR Tools to their particular case study area. While this option may be more suited to academic or more technical users, it ensures that the STAR Tools can potentially be used for any location, and full guidance is provided regarding the default parameters and model assumptions.

The technical development of the STAR Tools involved representing the two underpinning models as web-based tools. Server side, the processing is carried out in PHP running on an Apache server with MapServer. Spatial processing is carried out using GDAL/OGR and MapScript. Data is stored in a MySQL database. AJAX techniques are used to communicate between the client- and server-side scripts. Web Map Services and Web Feature Services are used to serve spatial data to the front end.

Since the STAR Tools were launched in early 2012, they have had 1,100 unique visitors, with over 200 progressing to the results page.[2] Regarding the origin of users, 64 % of visitors are from the UK, 5 % from the USA, and smaller numbers

[2]Unique visitors are defined as an individual user (or computer). Statistics were taken in December 2013.

were from Brazil, Spain, Belgium, and other countries. Information captured by the optional online questionnaire reveal that the STAR Tools have been used by policymakers, researchers, and green infrastructure professionals to guide policy and for academic research purposes.

Application of the STAR Tools to Inform The Mersey Forest Plan

The Mersey Forest is a community forest in North West England, covering 1,370 km^2. Established in 1991, it is a partnership of local authorities, national government agencies, land owners, businesses, and local communities. Its vision is to get "more from trees" to help make Merseyside and North Cheshire one of the best places to live in the country. The partnership has planted over nine million trees and doubled woodland cover since 1991, with three times more trees planted than the England average. This has attracted investment, boosted health and well-being, and improved the local environment.

The Mersey Forest Plan is the long-term and strategic guide to the work of The Mersey Forest team and partners. While it is not a statutory planning document in its own right, under the National Planning Policy Framework "an approved community forest plan may be a material consideration in preparing development plans and in deciding planning applications" (DCLG 2012). The Mersey Forest Plan was first written in 1994, updated in 2001, and has been refreshed again in 2014.

Since the earlier versions of the plan, climate change has risen up the policy agenda. In the early versions there is a brief acknowledgement of the "local and global atmospheric benefits" of trees and woodlands. In addition, reference is made to what we would now recognize as both the mitigation and adaptation benefits of trees and woodlands; specifically, "forestry locks up carbon and offsets other carbon dioxide emissions, helping to reduce global warming. Forests also have more local benefits in filtering out air pollutants, especially dust, reducing noise and acting as windbreaks. The shelter they provide will also improve the local climate of open spaces and has been shown to reduce the cost of heating buildings" (The Mersey Forest 1994, p. 16).

There was a clear need, which was recognized by The Mersey Forest partners, for climate change to have greater prominence in the refreshed plan. As such, it features as one of 20 policies set out under the headings "Who, What, How and Why" and is also cross-referenced in many of the other policies. The specific policy on climate change states, "We will safeguard, plant and manage trees and woodlands for their role in climate change mitigation, adaptation, and resilience – such as providing urban cooling, carbon storage, flood alleviation and water management, helping wildlife adapt, low carbon fuels and products, sustainable travel routes, and outdoor recreation opportunities. We will design, plant and manage them to increase their resilience to potential climate change impacts, such as changing pests and diseases" (The Mersey Forest 2014, p. 52).

The STAR Tools and the Surface Temperature Tool in particular provided evidence to support this policy. The Surface Temperature Tool was run for the

210 wards within The Mersey Forest for the baseline climate (1961–1990) and for the 2050s high emissions scenario (at the 10 %, 50 %, and 90 % probability levels). The default temperature scenarios supplied with the tool (available for North West England) were used. It was also run for the current land cover scenario (again, using the default values supplied) and for two further scenarios where 10 % green cover was either added or removed. When green cover was added, the same percentage was removed firstly from other impervious surfaces and then, if this did not meet the full 10 %, sequentially from major roads, buildings, and bare soil or gravel (and vice versa for when green cover was removed). In a few instances, in wards where either green cover was already above 90 % or below 10 %, it was not possible to add or remove the full 10 % green cover, and therefore, green cover was only added or removed to the maximum amount possible.

Since the Surface Temperature Tool was run for 210 case study areas (wards), the output was mapped using GIS and features within the plan (Fig. 7). The results found the hottest ward to be Liverpool Central, with a maximum surface temperature of 31.7 °C, whereas the coolest ward is Tilston in Cheshire West and Chester at 18.3 °C. There is a surface temperature difference of 13.4 °C between the hottest and coolest wards. These are also the wards with the lowest and highest green cover

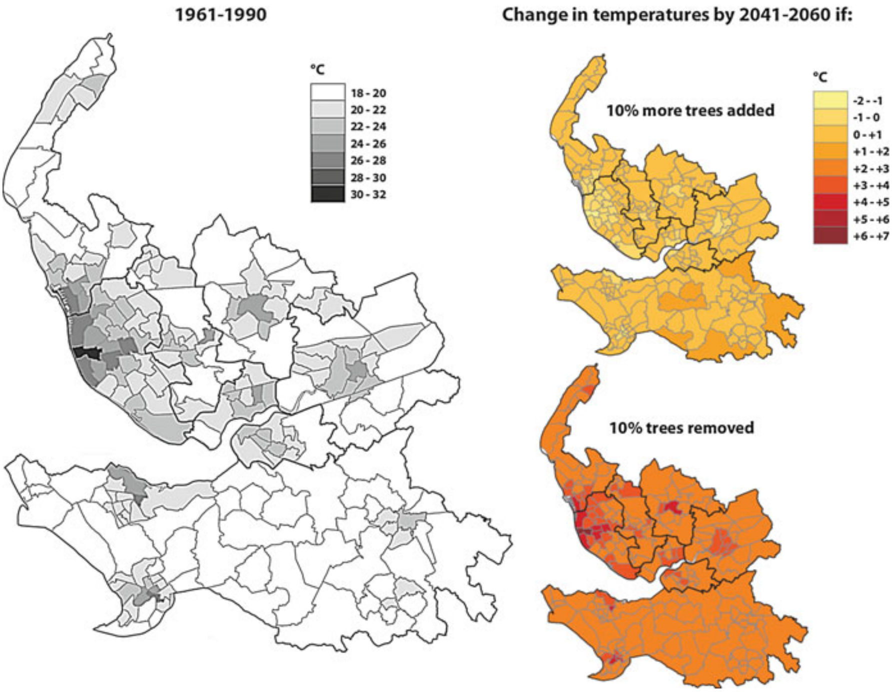

Fig. 7 Maximum surface temperatures on a hot summer's day (98th percentile summers day) (Mapped at the ward level; the 2041–2060 mapping used is for the 2050s high emission scenario, at a 50 % probability level) (© Crown copyright and database right 2012 Ordnance Survey 100031461)

(Liverpool Central is 16.7 % green, whereas Tilston is 97.7 % green). By the 2050s (at a 50 % probability level), the maximum surface temperature in Liverpool Central increases to 33.9 °C (2.2 °C hotter than in 1961–1990). Removing green cover from this ward would further exacerbate the situation; if 10 % green cover is removed, then the maximum surface temperature in the 2050s would be 38.5 °C (6.8 °C hotter than the maximum surface temperature in 1961–1990 with current land cover). However, adding green cover can help to ameliorate the situation; if 10 % green cover is added, then the maximum surface temperature in the 2050s would be 30.6 °C (1.1 °C cooler than the maximum surface temperature in 1961–1990 with current land cover).

The Surface Temperature Tool output was used to support the argument in The Mersey Forest Plan that increased tree planting will provide shade and evaporative cooling that help keep neighborhoods cooler and ensure that towns and cities continue to be healthy, comfortable, and attractive places to live, work, visit, and invest. The results can also be analyzed further by The Mersey Forest team in order to support ongoing activities in delivering the plan.

Conclusions: Lessons Learned and Key Challenges

The overall aim of the GRaBS project was to enhance local and regional planning policy in respect of climate change adaptation. The Assessment Tool is a useful decision-aiding tool, enabling support of the sharing of knowledge and expertise and helping to build the evidence base available to decision-makers and other stakeholders when developing adaptation plans and strategies. Similarly, the STAR Tools can be used to inform climate adaptation plans, green infrastructure plans and strategies, as well as local plans and developments.

Since planning is an integrative data-driven activity to enable effective decisions (Stillwell et al. 1999 cited in Dragicevic and Balram 2004), data availability, quality, and scale are key issues. It is notable that the GRaBS Assessment Tool local partner level tools vary in their comprehensiveness to assess risk and vulnerability based upon the existing spatial data that has been collected. The experience of developing the tools has highlighted the need for a common framework to help identify, collect, distribute, share, and prioritize the data that is required to inform the evidence base and enable a more harmonized approach to spatial planning for adaptation to climate change. This would need to be flexible to enable modification to the user's particular location, specifically in terms of context-specific vulnerability and climatic hazards.

The process of developing the Assessment Tool was invaluable for the GRaBS partners, particularly in helping to build bridges between departments (both internally and externally) during collation of spatial data. A key finding of the project was the need to break down silos between departments in order to gather holistic evidence of the need to act on adaptation. A key lesson is the importance to invest in a collaborative development process with the user, not only because the user can benefit significantly from this process, but also to ensure that resulting tools are not donor-centric, and the end product is provided in an accessible format for the intended user.

Generic challenges have been raised previously in relation to applying a PPGIS approach and are applicable to the GRaBS web-GIS tools – firstly, the cost and time involved in maintaining the currency of tools, including updating the spatial data and information. When developed, the STAR Tools included input data for the complete region of North West England; however, the ongoing data license for the soils input data remained too excessive, and this area was thus reduced to the Mersey Belt area. Further, while the importance of ensuring that the development and maintenance of the Assessment Tool continued beyond the GRaBS project was identified at an early stage, a funding stream through which this could be supported was not secured. The Assessment Tool is hosted as an open-source project at the University of Manchester and is available for use in other case study areas by changing the spatial data and associated metadata – although this requires knowledge of the Google Maps' API and JavaScript programming. Further work in the future could investigate how the Assessment Tool could be easily updated and edited by nonspecialists, to keep it up to speed with changing knowledge and the underlying spatial data.

Secondly, restrictions due to license agreements and confidentiality of sensitive data are a challenge to optimize access to information for the public. Free and open-source tools may conflict with the license agreements of many geospatial datasets (both public and private sectors), constraining the amount of data that can be included in the tool, thereby limiting its effectiveness. The Assessment Tool included a function to add data locally, thereby addressing this issue to some extent. The STAR Tools provide a modeling environment and were designed to enable application in any location, relying more upon user input data and thus minimizing the problem of license restrictions.

A third challenge in developing web-GIS tools is balancing the performance with data resolution. The Assessment Tool achieved fast performance by outputting spatial GIS data into an image format to speed up the map rendering process for the user. However, this approach meant that other useful web-GIS functionalities were restricted, such as changing data classifications or color schemes. Balancing user-friendliness with flexibility was also important in the STAR Tools development. Since the STAR Tools are complex scientific models, it was important that casual users were able to produce their outputs without having to consider or understand the full complexities of the model while also allowing more comprehensive users to interact with all underlying model parameters if they so desired.

A fourth challenge is providing enough information for the user to be able to apply the tool and interpret the data or output effectively. Detailed notes and guidance materials (including storylines) provided for the GRaBS Tools go some way to aiding this issue, but training events may also be beneficial, both to enhance understanding of the tools and ensure greater application. A more recent review of tools by Climate UK (2012), which included review of the Assessment Tool and

STAR Tools, suggested that there is little demand from UK stakeholders for new tools but more demand in terms of awareness raising and use of existing tools, including clear guidance on how the tools can be best applied. As the STAR Tools were released toward the end of the GRaBS project, buy-in from GRaBS partners was limited, and encouraging stakeholders to use the tool is challenging. Despite efforts to publicize the STAR Tools, usage remains low relative to the investment in developing the tools. Creation of a "toolbox of tools" by national and cross-sectoral organizations would therefore be useful to signpost stakeholders to the tools.

A final challenge for web-GIS tools is the fast pace of change in technology. When the Assessment Tool was envisaged, Google Maps was the only viable mapping Application Programming Interface (API). Since then, a number of other APIs, including Bing and OS OpenSpace have arisen, with functionality advancing at an unchecked rate. Additionally, post-GRaBS, a significant change in Web Map Services (WMS) in the UK in particular has occurred, with national organizations shifting to deliver their spatial data via WMS. Linking to the spatial data via WMS means there is no need to keep a local copy of the data that becomes outdated. While challenging, these fast changes are also very encouraging for the development of web-GIS tools and enhancing public participation in planning.

In terms of the future development of tools for climate change adaptation planning in cities, it is clear that the Public Participatory ("PP" in PPGIS) element could be advanced much further. Additional functions for the Assessment Tool such as push pins (to enable highlighting of locations of interest) and comment boxes could be applied to enable a more interactive facility, which could be extremely effective when utilizing the tool for community participation events. Gathering of user experiences and evidence could be particularly beneficial for climate change adaptation planning. For example, crowdsourcing local flooding evidence may be very useful to verify modeled flooding hazard outputs and official flood records utilizing the geo-referencing capabilities within social media applications.

Finally, Climate UK (2012) highlights that the greatest demand from existing tools is to help with prioritizing clear next steps and actions. Many tools, including the Assessment Tool and STAR Tools, are very effective in their ability to raise awareness about climate impacts and the need for adaptation responses, though they do not necessarily aid prioritization of risks and opportunities. This is an area that should be considered in future developments.

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