Science for Sustainable Societies

Kazuhiko Takeuchi
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Hirotaka Matsuda
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Resilient Asia

Fusion of Traditional and Modern Systems for a Sustainable Future

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ISSN 2197-7348 ISSN 2197-7356 (electronic)
Science for Sustainable Societies
ISBN 978-4-431-56595-6 ISBN 978-4-431-56597-0 (eBook)
https://doi.org/10.1007/978-4-431-56597-0

Library of Congress Control Number: 2017960439

Printed on acid-free paper

This Springer imprint is published by the registered company Springer Japan KK, part of Springer Nature.
The registered company address is: Shiroyama Trust Tower, 4-3-1 Toranomon, Minato-ku, Tokyo 105-6005, Japan

Acknowledgments

We would like to express our sincere gratitude to our collaborative institutes, University of Peradeniya, Gadjah Mada University, and Vietnam National University, for implementing a project on “strategy to enhance resilience to climate and ecosystem changes utilizing traditional bio-production systems in rural Asia” (FY 2011–2013). All case studies in this book were carried out as part of the project, and we would like to thank the Ministry of the Environment, Japan, for the financial support. We are also grateful for all government agencies, local researchers, practitioners, local communities, and people who participated in our field surveys in the study countries.

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Chapter 1
Introduction: Enhancing Resilience Against Climate and Ecosystem Changes in Rural Asia

Kazuhiko Takeuchi, Osamu Saito, Hirotaka Matsuda, and Geetha Mohan

Abstract This chapter introduces the influence of climatic and ecosystem changes in agricultural communities across rural Asia including Indonesia, Sri Lanka, and Vietnam using both quantitative and qualitative methods. Across various case studies in three major themes, this chapter outlines the structure and approach to lead the potential solutions to the problems that arise in the development of adaptation of bioproduction systems to climatic, social, and ecological changes. The solutions include methods to improve potential adaptive capacity and agroforestry systems, and an integrated irrigation water management to increase natural and livelihood resources. Following chapters represent a synthesis of sustainable traditional and modern systems and the methods operative in rural Asia, which identifies the advantages of mosaic systems to enhance resilience and promote sustainable development.

Keywords Climate change · Ecosystem · Resilience · Mosaic systems · Sustainable development · Rural Asia

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K. Takeuchi et al. (eds.), *Resilient Asia*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56597-0_1

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Climate change and transformations in ecological systems affect bioproduction mechanisms, which are the main sources of livelihood in almost all developing countries. These systems are particularly vulnerable to the direct and indirect impact of ecosystem and biodiversity changes (Dharmarathna et al. 2012); consequently, people residing in these countries are the most vulnerable to such changes. Developing countries are characterized by rapidly increasing population and urbanization. It is therefore necessary to establish methods to increase the resilience to climate and ecosystem changes in production and processing of food and fiber in these countries. As a direct consequence, it is recognized that enhanced resilience to climate and ecosystem changes is essential to establish sustainable societies. Although climate and ecosystem changes should be addressed in an integrated manner because of their interconnectivity, they have been considered separately in the global community. Issues of climate change have been discussed in the Intergovernmental Panel on Climate Change (IPCC), and ecosystem changes are the focus of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES).

In order to formulate strategies to address climate change, economic, environmental, social, political, and cultural complexities must be fully understood (Clements et al. 2011). An effective adaptation to these wide-ranging changes is an approach that prepares a community for a new or modified environment without simplification or the loss of structure and mechanisms (CBD 2006). An example of such a strategy is the agroecological farming approach, which provides a range of productive and sustainable practices that cause minimal negative environmental and social impacts while seeking to sustain productivity (Altieri and Nicholis 2005; FAO 2008; IAAST 2008; Ensor 2009; De Schutter 2010). This approach uses both the traditional knowledge of farming together and selected modern technologies to manage diversity, incorporate biological principles and resources into farming systems, and intensify agricultural production (Clements et al. 2011). The combination of indigenous farming knowledge and selected modern technologies can replenish natural resources and improve long-term resilience and agricultural productivity. The development of this method has been a major factor in improving economic and social benefits. Several scientific communities and international agencies, including International Assessment of Agricultural Science and Technology (IAAST), Food and Agriculture Organization (FAO), United Nations Environment Programme (UNEP), Biodiversity International, and IPBES have emphasized the importance of developing a scientific approach that considers traditional knowledge (IAAST 2008; UN-FAO 2008; Altieri and Nicholis 2005; SARD 2007; and Diaz et al. 2015).

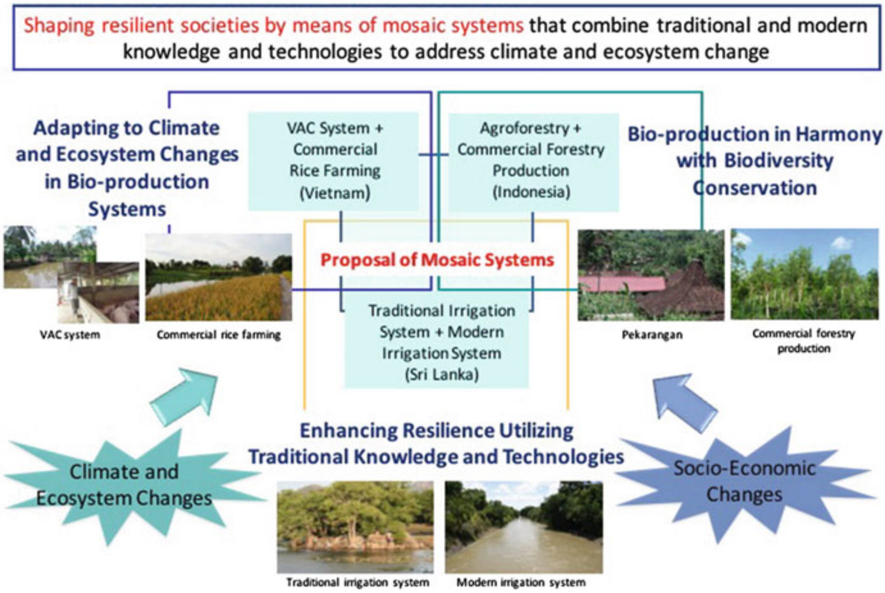

Fig. 1.1 Proposed mosaic systems that combine traditional and modern technologies to address climate and ecosystem changes (Adapted from Takeuchi et al. 2016)

A model based on a mosaic system can contribute to building sustainable societies that combine traditional practices and modern technologies to address climate and ecosystem changes as well as socioeconomic change. The understanding of the proposed mosaic systems is addressed in detail through the illustration of a number of successful cases (Fig. 1.1).

This book was designed to document and summarize 3 years of extensive research conducted under Climate and Ecosystems Change Adaptation Research in Asia (CECAR-Asia), a project funded by the Ministry of the Environment, Japan. The principal objective of this project is to propose measures to enhance the resilience of rural production systems in three countries in rural Asia, namely, Indonesia, Sri Lanka, and Vietnam. Research teams from the University of Tokyo, Japan; the United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS), Tokyo, Japan; and the Research Institute for Humanity and Nature (RIHN), Kyoto, Japan, conducted research in collaboration with their counterpart universities in the three countries, namely, Gadjah Mada University, Indonesia; University of Peradeniya, Sri Lanka; and Vietnam National University, Vietnam.

In each chapter, the authors examine the influence of climatic and ecosystem changes in agricultural communities across Asia using both quantitative and qualitative methods. Each chapter identifies the merits of applying organic methods to both commercial large-scale production and traditional production systems to increase resilience and promote sustainable development. Through various case studies, this book offers potential solutions to the problems that arise in the development of an integrated framework comprising modern and traditional systems in order to enhance the productivity and total system resilience. The collection of chapters in this book represents a synthesis of sustainable traditional and modern systems and the methods operative in rural Asia. In this book, there are three major thematic clusters: (1) adaptation of bioproduction systems to climatic, social, and ecological changes (Chaps. 2, 3, and 4), (2) methods to increase potential adaptive capacity and enhance homegardens agroforestry system (Chaps. 5 and 6), and (3) development of integrated irrigation water management to increase water resources, productivity of crop land, and livelihood of farmers (Chaps. 7 and 8).

The first thematic cluster focuses predominantly on the adaptation of biological production systems to climatic and ecological changes. The measures for reducing vulnerability and enhancing resilience to climate change include increasing the resilience of the natural environment, ecosystems, and social systems. Chapter 2 assesses and clarifies the relationship between vulnerability of rice production, climate risks, and seawater intrusion. To reduce vulnerability, formal interventions include prevention of risk to individual paddy fields and realizing assured irrigation management. Chapter 3 describes the importance of social factors in bioproduction systems such as risk behavior of farmers, social networks, and credit constraints are considered as the key determinants. Chapter 4 discusses measures for reducing vulnerability and enhancing resilience to climate change and sustainability, such as increasing the resilience of natural environments, ecosystems, and social systems, improving urban governance for climate change adaptation, and promoting the transformative capacity from climate change to sustainable development opportunities in Da Nang City, Vietnam.

Adaptive capacity and agroecological systems are the key issues highlighting the societal facets of climate change. This is discussed in the second thematic cluster (Hinkel 2011). Chapter 5 explains the farmers' adaptation strategies for climate change in unfavorable upland areas in Indonesia. Chapter 6 reviews the components, diversity, temporal layout, functions, spatial layout, and scale of homegardens in Indonesia, Sri Lanka, and Vietnam. It focuses on Sri Lanka as a case study to understand the drivers of change in these homegarden systems and proposes potential strategies to improve homegarden systems and livelihood in rural areas.

The third thematic cluster (Chaps. 7 and 8) illustrates the feasibility of fusing traditional and modern systems through building mosaics of traditional and new systems. As an example, the Deduru Oya irrigation project in North Western Province in Sri Lanka is studied as a model of integration of modern and traditional irrigation systems to improve crop intensity and resilience. This project shows that by incorporating the existing traditional irrigation systems, water irrigation requirements for paddy cultivation in the canal irrigation area are accomplished successfully. It should be noted, however, that modern systems can also meet the irrigation demand when the integration of existing distributed small tanks increases the resilience during extreme drought conditions and much-needed macroscale/microscale incorporation with an emphasis on autonomy at the microscale.

Finally, Chapter 9 concludes this book by synthesizing the key findings and providing recommendations and future direction to facilitate the application of our integrated approach to enhance resilience against climate and ecosystem change beyond the selected study areas.

References

Altieri MA, Nicholis CI (2005) Agroecology and the search for a truly sustainable agriculture. UNEP, Mexico

CBD (Convention on Biological Diversity) (2006) Guidance for promoting synergy among activities addressing biological diversity, desertification, land degradation and climate change, Technical series no. 25, Secretariat of the Convention on Biological Diversity (CBD), Montreal, 43 pp

Clements R, Haggar J, Quezada A, Torres J (2011) Technologies for climate change adaptation – agriculture sector. In: Zhu X (ed). UNEP Ris. Centre, Roskilde

De Schutter O (2010) Report submitted by the Special Rapporteur on the right to food to the Human Rights Council, 17 December

Dharmarathna WRSS, Herath S, Weerakoon SB (2012) Changing the planting date as a climate change adaptation strategy for rice production in Kurunegala District, Sri Lanka. Sustain Sci 9:103–111

Diaz S et al (2015) The IPBES conceptual framework – connecting nature and people. Curr Opin Environ Sustain 14:1–16

Ensor J (2009) Biodiverse agriculture for a changing climate. Practical Action, Rugby

FAO (2008) Climate change adaptation and mitigation in the food and agriculture sector. Technical background document from the expert consultation held on 5–7 March 2008. Food and Agriculture Organization, Rome

Hinkel J (2011) Indicators of vulnerability and adaptive capacity: towards a clarification of the science-policy interface. Global Environ Chang 21:198–208

IAAST (International Assessment of Agricultural Science and Technology) (2008) Summary for decision makers of the global report, approved by 58 governments in Johannesburg, April 2008, see Key Finding 7; see Wezel A et al A quantitative and qualitative historical analysis of the scientific discipline of agroecology. Int J Agric Sustain 7(1):3–18

SARD (2007) Policy brief 11. Sustainable Agriculture and Rural Development

Takeuchi K, Matsuda H, Saito S, Herath S, Naito D, Mohan G (2016) Building resilience in rural Asia: combining traditional and modern bioproduction systems, the challenges of agro-environmental research in monsoon Asia, NIAES series no. 6, pp 13–25

Chapter 2
Preliminary Assessment of Rice Production in Coastal Part of Red River Delta Surrounding Xuan Thuy National Park, Vietnam, for Improving Resilience

Akihiko Kamoshita, Yen Thi Bich Nguyen, and Van Thi Hai Dinh

Abstract Rice production in Giao Thuy district surrounding Xuan Thuy National Park at the estuary of Red River, Vietnam, was assessed by local rice statistics (1990–2012), historical climate (1961–2010) and salinity (2003–2012) recordings, farmer interviews, and on-farm yield and salinity trials, in order to clarify (1) vulnerability and resilience to climate hazards and seawater intrusion and (2) differences in rice production in buffer zone of Xuan Thuy National Park as compared with the outer zone. Intensive double rice cropping with small land size characterized the target site. Historical yield rapidly increased from the 1990s particularly for spring rice. Incidences of flood and pest seriously reduced yield of summer rice in some years (i.e., 2005, 2009), together with numerous various climatic damages perceived by farmers. Mean maximum air temperature has increased by 0.3 °C per decade, while its direct effects on rice yield were not conspicuous. Seawater intruded to longer distance toward upstream from the estuary: salinity became high at the intake gates nearby sea (i.e., 2.1% at Con Nhat) which have been replaced with the new upstream intake gate. The salt concentration of standing water in the 28 selected paddy fields was generally maintained lower. Rice yield in the fields nearby the river/coast dyke was lower than those far from the dyke. Inputs of inorganic fertilizers and pesticides were equally high in buffer zone of Xuan Thuy National Park as in the outer zone. Possible strategies to improve resilience of rice production in Giao Thuy were discussed.

Keywords Adaptation · Buffer zone · Climate change · Intensification · Red River Delta · Rice production · Seawater intrusion

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K. Takeuchi et al. (eds.), *Resilient Asia*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56597-0_2

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2.1 Introduction

Red River Delta is one of the most productive agricultural areas located in the northern part in Vietnam, with the 74% of agricultural land used for rice cultivation (573,900 ha), producing one thirds of rice in Vietnam (GSO 2012; Young et al. 2002). The coastal area of Red River Delta is however known to be prone to natural coastal hazards, especially under climate change associated with sea level rise and increased intensity of storm, monsoon, and typhoon. It was alarmed that sea level rise was significant in Asia including Vietnam (Hanh and Kurukawa 2007; Kotera et al. 2008; Tuong et al. 2003; Wassmann et al. 2004). This in combination with decreasing trend of water level in dry season in the Red River (due to dam construction and decreased rainfall in dry season) (Giang et al. 2013) may have lead seawater intrusion deeper into the River estuary. Only few studies have presented future scenarios of climate change in Red River Delta (Thai and Van 2011; Vu and Bui 2006), but without examination of seawater intrusion and field and household surveys of local realities. The local information of coastal part of Red River Delta is very limited to assess vulnerability of rice production, preventing to build strategies to improve resilience of rice production to climate hazards and seawater intrusion.

Vietnam is known to be transformed from rice-importing country to one of the top rice-exporting countries with the highest rice yield among the tropical countries, which came from the government policy of agricultural intensification from the 1990s (Minot and Goletti 2000; Young et al. 2002). The intensification may have caused greater emission and load of agrochemicals such as inorganic fertilizers and pesticides to the surrounding environments. At the mouth of Red River Delta, there is a coastal wetland which provides unique landscape and rich biodiversity of migrating birds and marine creatures, as designated as Xuan Thuy National Park in 2003 by Vietnamese government and as the first core zone of the Red River Biosphere Reserve in 2004 by the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Cach 2005; Hong et al. 2007b, https://en.wikipedia.org/wiki/Xu%C3%A2n_Th%E1%BB%A7y_National_Park, http://vuonquocgiaxuanthuy.org.vn,). The front part of Red River Delta closer to and bordered with Xuan Thuy National Park is considered as a delicate zone in terms of production intensity and natural conservation, which were referred as "buffer zone" (Ebregt and Greve 2000). However, it is not known to what extent input level is saved in rice production system in the buffer zone in contrast with the other outer zone more distant from the national park.

In this study, we assessed characteristics of rice production in Red River Delta, most productive rice-growing area in Vietnam; we assessed its vulnerability to climate hazards in coastal part of Red River Delta, and we also assessed its spatial variation from Xuan Thuy National Park. Our objectives are (1) firstly to clarify relationship between vulnerability of rice production and climate hazards and seawater intrusion in order to make strategies for improving resilience to climate hazards and (2) secondly to characterize rice production in buffer zone of Xuan Thuy National Park with comparison to the outer zone in order to consider zone-specific information to improve resilience in rice production.

2.2 Site Description

2.2.1 Multiple-Scale Survey

At multiple scales of district, commune, household, and field, information about rice production was collected.

2.2.1.1 Giao Thuy District and Xuan Thuy National Park in Nam Dinh Province

The study site is about 150 km southeast from Hanoi, located in Giao Thuy district, one of the ten subdivisions of Nam Dinh province at the mouth of Red River (Fig. 2.1). Among the four coastal provinces (Nam Dinh, Thai Binh, Ninh Binh, and Hai Phong) of the Red River Delta, Nam Dinh has the longest coastal line and also has estuaries of Red River and hence considered to be most influenced by coastal hazards and possible seawater intrusion. Giao Thuy district is chosen, as it has a Ba Lat estuary, one of the four main estuaries of Red River. Giao Thuy district has 32 km of coastal line, with the area of 23,000 ha and 22 communes (including two towns) of the population of about 210,000 in 2010.

Ba Lat estuary is bordered with Xuan Thuy National Park, which is divided by the core zone (7100 ha) where environmental conservation is mandate and agricultural activities (cf. including fishery) are prohibited, and the buffer zone (8000 ha) surrounding the core zone up to about 10 km distance where agricultural activities are permitted, but environmental conservation needs to be considered for the national park (Dao et al. 2007). Five communes out of the 22 communes are located in the buffer zone (Giao Thien, Giao An, Giao Lac, Giao Xuan, and Giao Hai). In

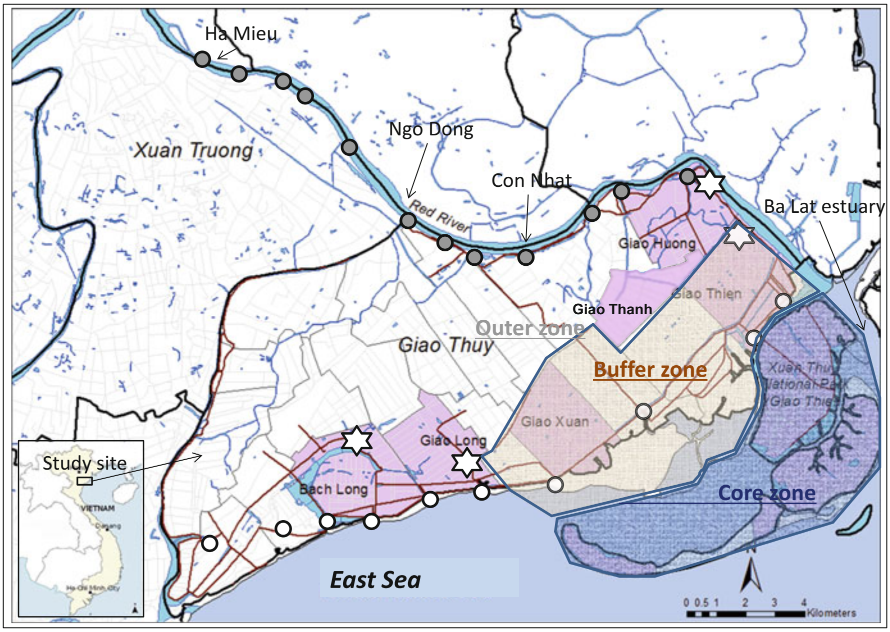

Fig. 2.1 Study location of Giao Thuy district, Nam Dinh province, Vietnam. Sets of paddy fields (stars) were selected in four communes (Giao Thien, Giao Huong, Giao Long, Bach Long) for case studies. Black and white circles indicated irrigation and drainage gates, including Con Nhat, Ngo Dong, and Ha Mieu irrigation gates. Core zone and buffer zone of Xuan Thuy National Park and outer zone were marked. Two communes (Giao Thien, Giao Xuan) from buffer zone and tree communes (Giao Huong, Giao Thanh, Giao Long) from outer zone were selected for the comparison. The map is made by ArcGIS using the original source of Vietnam administrative/road/river boundary database and the irrigation map of Xuan Thuy irrigation company

the outer zone (outside of the buffer zone, more distant from Xuan Thuy National Park), agriculture is practiced in conventional manner without specific regulation.

2.2.1.2 Communes and Fields in Giao Thuy District

We selected two communes from the buffer zone (Giao Thien, Giao Xuan) and three communes from outer zone (Giao Huong, Giao Thanh, Giao Long) for commune-level statistical survey and for questionnaire survey (as explained in Sects. 2.3.3 and 2.3.4). Giao Thien, Giao Xuan, and Giao Long were coastal communes. Giao Huong and Giao Thien were located at the side of Red River.

We selected 28 paddy fields in Giao Thuy district: 7 fields from Giao Thien, 8 fields from Giao Huong, 6 fields from Giao Long, and 7 fields from Bach Long communes. Bach Long is another coastal commune in the outer zone where many salt-producing fields are located.

2.2.2 Climate, Geography, and Agriculture

Giao Thuy district has subtropical monsoon climate with the distinct dry (November to April) and rainy (May to October) season. Topography of the area is flat, gently sloped from north to south, with densely distributed river and canal systems. Irrigation water source mainly comes from the Red River which begins in China's Yunnan, flowing southeastward to Vietnam, passing through Giao Thuy district at downstream with the length of about 18.7 km before emptying into the Gulf of Tonkin at Ba Lat estuary (Fig. 2.1). Water flow in the river is lowest between February and April (Thanh et al. 2004).

The agriculture land in Giao Thuy is 16,681 ha (2010), in which crop area is nearly 60%, forestry area 15%, and aquaculture area 25%. Agricultural sector contributed almost 50% to the economy of and involved more than 75% of the population of the district (Giao Thuy DPC 2010). Rice production is a main agricultural activity in the district. There are two crops of rice in a year, the spring rice (vu Chiem in local Vietnamese language) from January to June and the summer rice (vu Mua) from July to November. In the present study site located in the lower part of Red River Delta nearby the coast, the land is fallowed from November to January unlike the upper part of Red River Delta where winter crop (peanut, soybean, maize, vegetable, etc.) is grown.

2.2.3 Seawater Intrusion

The intensity of seawater intrusion into the river is affected by diurnal tide of the Gulf of Tonkin with tidal range of about 4 m. There is a high and low tide occurring in a day and a spring and neap tide occurring in a month. Due to low water level in the river in dry season, seawater intrudes into the river with longer distance in comparison with that in rainy season (Vu and Bui 2006). Salinity level in the river is monitored for making decision of opening irrigation gate. Salinity level should be lower than 0.1% (Nguyen TBY communication with Xuan Thuy Irrigation Company 2013). According to the district and/or commune leaders' perception, rice fields located near by the dyke (both sea and river) are likely to be affected by salinity through the seepage of salt water through dyke and/or irrigation/drainage gates (Table 2.1).

2.3 Survey Methods

Environmental parameters such as historical climate data, salinity levels of Red River and paddy fields, rice yield data of various scales, and household data are collected by using the following methods.

Table 2.1 Paddy area and salinity-affected area in five communes located nearby river and coastal dyke in Giao Thuy district, Nam Dinh province, Vietnam

No	Commune	Location	Paddy area (ha)	Salinity-affected area[a] (ha)	(%)
1	Giao Thien	Close to river mouth/dyke	425	10	2.4
2	Giao Huong	Close to river mouth/dyke	563	15	2.7
3	Giao Xuan	Close to coastal dyke	439	41	9.3
4	Bach Long	Close to coastal dyke	3	0	0
5	Giao Long	Close to coastal dyke	435	57	13.1

[a]The affected area was estimated through perception by the commune leaders in 2012

2.3.1 Historical Climate Data Analysis

Daily maximum and minimum temperature and daily rainfall from 1961 to 2010 in Nam Dinh weather station (20°26′N; 106°09′E), which contains recordings of the longest duration in Nam Dinh province and about 30 km from the northwest of the study site of Giao Thuy district, are collected. Mean, standard deviation, and coefficient of variances of the climate data are calculated for 1961–2010. The significance of trends of maximum and minimum temperature and rainfall are tested using regression analysis over years.

2.3.2 Irrigation Management Data Analysis

Daily maximum salt concentration and irrigating duration, recorded by staff of the Xuan Thuy irrigation company from 2003 to 2012 at three irrigation stations located along the Red River with different distance from Ba Lat estuary to upstream in Nam Dinh province (13.5 km for Con Nhat, 17.8 km for Ngo Dong, and 27.5 km for Ha Mieu; Fig. 2.1), are collected for analysis of level of salinity intrusion in the study area. Maximum salinity concentration is measured every day at high tide. The measurements of salt concentration in these stations are mainly for irrigation purpose. Both salinity and irrigation data of 2011 at Con Nhat station are not available due to the maintenance. Salinity intrusion normally does not occur in rainy season due to large discharge of freshwater from upstream, and hence, the data only for dry season from December to May are collected.

2.3.3 Statistical Information

Historical yield data for spring and summer rice from 1990 to 2010 in Giao Thuy district is collected (Giao Thuy district 2010).

Statistical information on basic demography (e.g., household number, population) and land use (e.g., total area, rice-planted area, fishery area, percentage of labor on agriculture and fishery) and agricultural production (e.g., monthly income, productivity of major crops, change of crop pattern in recently years) for the five communes (Giao Thien, Giao Xuan as the buffer zone, Giao Huong, Giao Thanh, Giao Long as the outer zone) is collected from district report in 2012 (Giao Thuy DPC 2012) and from interviews with the head and staff of Department of Agriculture and Rural Development of Giao Thuy district and five chiefs of Commune People's Committee in September 2011 and February 2013.

2.3.4 Questionnaire Survey

A questionnaire about agricultural production and livelihood is asked to approximately 40 randomly selected households for each of the five communes in Giao Thuy district in October 2011 (in total 200 respondents). Monthly income of each household is surveyed from the four main job groups: crop cultivation (rice, cash crop, fruits), livestock raising (pig, cow, chicken, duck), fishery activities (aquaculture of clams, shrimp, crab, and fish and capture of shrimp, crab, and others), and nonagricultural activities (service, tourism). Application rates of nitrogen fertilizer in 2011 and number of times of pesticide application in 2006 and 2011 for rice production are surveyed.

The significance of average income from different sources between buffer zone communes and outer communes was tested using independent sample T-test, and the comparison of the key data (e.g., income, fertilizer, pesticide occasions) within the five communes was done by one-way ANOVA test in SPSS software.

2.3.5 Rice Production Case Analysis

Twenty-eight fields with different distance from the dyke/salt field (expecting with different salinity level according to farmer's perception; the closer to the dyke, the more likely affected by salinity), located in four communes (Giao Thien and Giao Huong located next to the Red River mouth; Giao Long and Bach Long located next to the sea; Fig. 2.1), are selected for monitoring salt concentration in standing water in the paddy field, rice management, and rice yields from 2011 summer rice to 2013 spring rice (in total four seasons). There were 11 combinations of rice cropping season and year and communes in total. Detailed information of the selected fields was described in Table 2.2.

Salinity level of standing water in the field is measured every 10 days by using salinity meter (SK-10S, Sato Keiryoki Mfg. Co., Ltd., Tokyo, Japan). Three readings are made in each measuring occasion for one field. Three quadrates (1 m $\times$ 1 m) are randomly selected at each field for sampling rice at maturing

Table 2.2 General information of the three groups of fields with different distance from the dyke or salt field (far, close, and outside) in the four communes (Giao Thien, Giao Huong, Bach Long, Giao Long) in Giao Thuy district. Salinity of water and rice yield were studied in total 28 fields from 2011 to 2013

Field groups by distance from the dyke (m)[a]		Field numbers[b]	Replicate numbers[c]	Studied seasons and years
Giao Thien				
Far from the dyke	500 ± 0	3	9	Summer 2011, spring 2012, summer 2012, spring 2013
Close to the dyke	77 ± 94	4	12	
Giao Huong				
Far from the dyke	175 ± 50	4	12	Spring 2012, summer 2012, spring 2013
Close to the dyke	53 ± 40	3	9	
Outside the dyke[d]	2	1	0	Summer 2012, spring 2013
Bach Long				
Far from salt field	1133 ± 206	6	18	Spring 2012, summer 2012, spring 2013
Close to salt field	700	1	3	
Giao Long				
Far from the dyke	293 ± 31	4	12	Summer 2012, spring 2013
Close to the dyke	4	2	6	
All the communes				
Far from the dyke/salt field	618 ± 444	17	51	
Close to the dyke/ salt field	118 ± 214	10	30	
Outside the dyke	2	1	0	
Total	402 ± 447	28	81	

[a]Average and standard deviation of the distance among the studied fields for each group in each commune were shown
[b]Field numbers for measurement of salinity of standing water in the fields
[c]Three rice samples were collected in each field except the riverside field outside the dyke in Giao Huong
[d]This field is located outside dyke next to the Red River (riverside field). The farmer cultivates shrimp in spring season (January to June) and rice (Nep Cao variety) in summer season (July to November)

time for grain yield and straw weight (air dry). Plant height and number of hills in each quadrate were measured. Information on crop management (i.e., variety; fertilizer type, amount, and splitting times; pesticide use; and other information affecting on grain yield) is obtained by interviewing the field owners at the end of each rice season.

ANOVA was made for yield using SPSS software according to the model to test the combinational effect of year, season, and commune, the effect of distance from dyke, and their interactions. Multiple comparisons among the 11 years, season, and commune combinations were made. T-test was also conducted for each of the 11 combinations between far and close fields.

2.3.6 Group Discussion

Group discussions with commune leaders are conducted in the four communes (Giao Huong, Giao Thien, Giao Long, and Bach Long; Fig. 2.1) where the 28 fields were selected for the rice production case analysis in October 2011 to obtain the information on (1) the major rice varieties grown and (2) the farmer recognition of extreme climate events and pest diseases incidences in their communes in Giao Thuy district.

2.4 Results

2.4.1 Assessment of Vulnerability of Rice Production to Climate Hazards

2.4.1.1 Climate Data

2.4.1.1.1 Trend and Variability of Temperature in Giao Thuy in 1961–2010

Annual mean maximum temperature during the period of 1961–2010 (50 years) is 27.0 °C. The highest mean maximum temperature is in July (33.0 °C), while the lowest mean minimum temperature is in January (14.4 °C) (data not shown). The highest coefficient of variation (more than 10%) is seen in February for both minimum and maximum temperatures. Annual average maximum and minimum temperatures significantly increased from 1961 to 2010 with 0.30 and 0.13 °C per decade (Fig. 2.2). The average values for spring rice season (January to June) showed similar increase trends with slightly larger degrees (0.32 and 0.21 °C per decade, respectively) (data not shown).

2.4.1.1.2 Trend and Variability of Rainfall in Giao Thuy in 1961–2010

Average total rainfall of spring rice, summer rice, and the whole year is 556, 1108, and 1692 mm, respectively, during the 50 years (data not shown). From May to October, monthly rainfall and number of wet days per month are greater than 180 mm and 9 days, respectively, with the highest monthly total rainfall in August and September. Although there is no statistical significance, total rainfall and number of wet days in the whole year show a slight declining trend (data not shown). Monthly rainfall in April and October also showed a significant decrease trend (14 mm and 25 mm per decade, respectively).

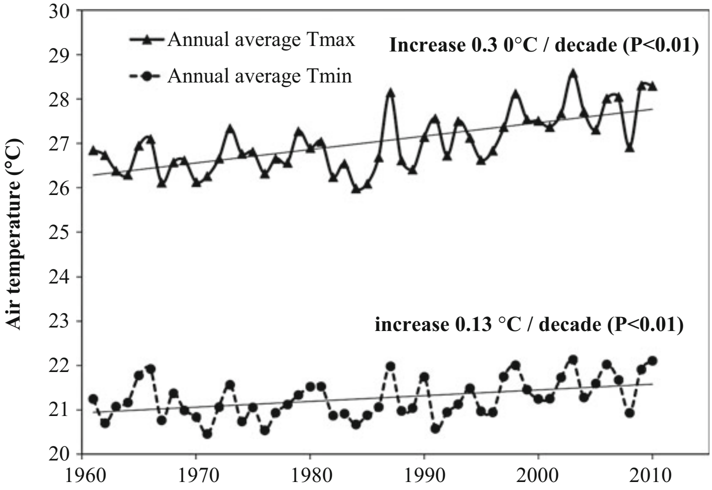

Fig. 2.2 Trend (°C per decade) of annual average maximum and minimum temperature during the period of 1961–2010 at Nam Dinh weather station

2.4.1.2 Salinity and Pumping Hours at Three Intake Gates in Red River

2.4.1.2.1 Salinity

Monthly average of maximum salinity concentration during the period of 2003–2012 is highest in Con Nhat gate (closest to the river mouth) (ca. 1% or higher in December and January and 0.7% in February to April), followed by that in Ngo Doc gate (second closest to the river mouth) (ca. 0.8% in December and January and 0.5% in February to April). The most upstream Ha Mieu gate has the lowest corresponding values (less than 0.2% in December and January and 0.1% in February to April) (data not shown). The seasonal highest salinity level in Ba Lat estuary occurs in January with the average maximum salinity concentration of 1.16% at Con Nhat, 0.87% at Ngo Dong, and 0.17% at Ha Mieu station. Salinity concentration varies from year to year in the three selected stations, but generally, there is an increasing trend (Fig. 2.3). During the period of 2003–2012, the highest salinity concentration is observed in 2010. The average maximum salinity concentration in January 2010 is up to 2.13%, 1.67%, and 0.67% at Con Nhat, Ngo Dong, and Ha Mieu station, respectively.

2.4.1.2.2 Pumping Hours

There are declining trends in the amount of operation hours from 2003 to 2012 for the two downstream stations (Con Nhat and Ngo Dong stations) (Fig. 2.4). The longest operation hours for spring rice season from January to May between 2003

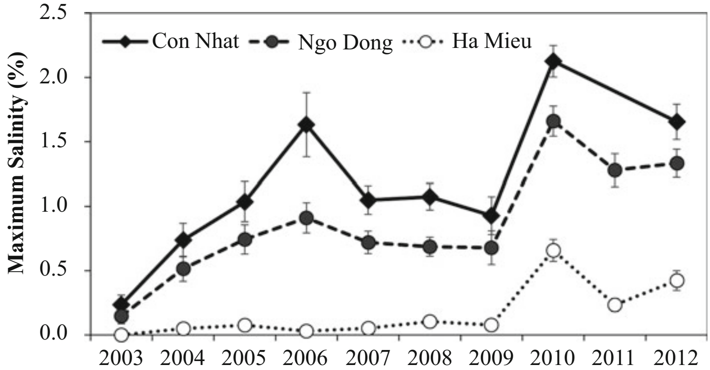

Fig. 2.3 Average of maximum salinity concentration in the three stations in January from 2003 to 2012 (error bars indicate SE) (data of 2011 was not recorded for Con Nhat station due to its maintenance) (Source: Xuan Thuy irrigation company)

and 2012 are observed in 2003 for both stations, with 561 h for Con Nhat and 639 h for Ngo Dong. The shortest amount of operation hours are in 2010, with only 89 h for Con Nhat and 131 h for Ngo Dong. The operation hours in Ha Mieu is longer than that in Con Nhat and Ngo Dong, especially after 2006. The longest hours are in 2008 with 639 h.

2.4.1.3 Overall Rice Production and Climate Hazards in Giao Thuy District

In general, rice yield in spring rice is higher and more stable than that in summer rice (Fig. 2.5). Rice yields in spring rice start steadily increasing from only less than 4 t/ha in 1990 and 1991 to consistently more than 7 t/ha after 1996. Rice yields in summer fluctuate about 4–5 t/ha, but the lowest yields are observed in 2005 and 2009, with only 2.5 and 2.8 t/ha, respectively.

Extreme climate hazards are noted such as heavy damages on summer rice production due to storm/flood in 2005 and 2009; massive death of seedlings and delaying transplanting time in spring rice 2008, 2010, and 2011 due to severe cold spell in January; and strong salinity intrusion leading to water shortage in 2009 and 2010 (Table 2.3). The damages due to pest and disease in summer rice 2009 (e.g., brown plant hopper, black-streaked dwarf rice) are severe.

Both hybrid and inbred rice from China and Vietnam are grown in Giao Thuy district (Table 2.4). The most popular hybrid rice in the area was Tap Giao variety from China such as Tap Giao 838 and Tap Giao 903. The advantages of these varieties are higher yield and resistance to lodging, but their taste is poor. Improved inbred varieties, with slightly lower yield but superior quality than Chinese hybrid varieties, are also popular such as BC15, TBR45 (from Vietnam), and Bac Thom 7 (from China). Among the traditional local photoperiod sensitive varieties, only

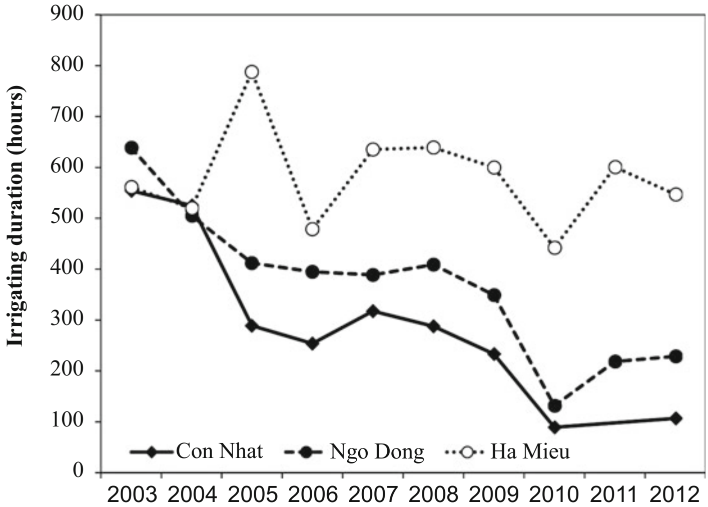

Fig. 2.4 Changes in irrigation duration in spring rice (January to May) over the period of 2003–2012 in the three stations (data of 2011 was not recorded for Con Nhat station due to its maintenance) (Source: Xuan Thuy irrigation company)

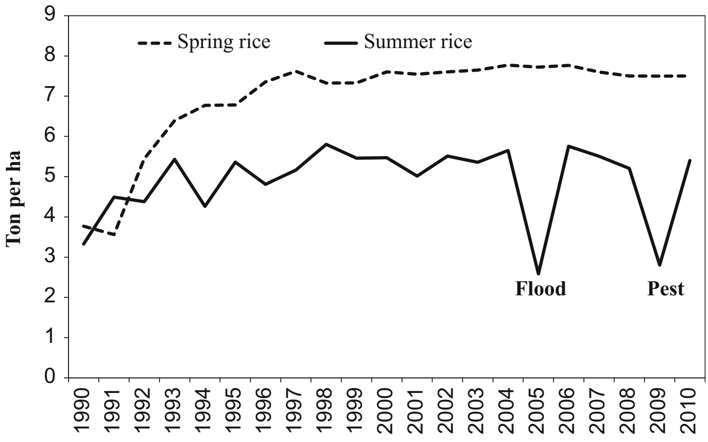

Fig. 2.5 Variation in rice yield in spring and summer seasons from 1990 to 2010 in Giao Thuy district (Source: statistical book of Giao Thuy district)

Nep Cao variety (glutinous rice) is grown in the lower area near by the dyke. For the 5 years from 2008 to 2012, average planting areas for hybrid and inbred rice varieties are almost equal for both spring and summer rice, with some yearly and seasonal variability; percentages of hybrid varieties are 67% for summer rice in 2008 and 60% for spring rice in 2010, while they are least in 2012 (i.e., 42 and 40% for spring and summer rice).

Table 2.3 Farmers' recognition of extreme climate events and pest incidences in Giao Thuy district, Nam Dinh province, Vietnam

Events	Time	Damages
Extreme climate event		
Storm and flood	October 1983	Large loss of life and damage on property
	October 1986	Large loss of life and damage on property
	June 2002	Damage on rice production
	September 2003	Damage on crop and aquaculture production and property
	August 2004	Dyke broken, people evacuation
	July 2005	Damage on rice production
	September 2005	Dyke broken
	August 2006	Dyke broken
	November 2008	Damage on rice production (near harvest)
	September 2009	Damage on rice production (near harvest)
	September 2011	Damage on rice production (reproductive stage)
Water shortage	October 2008–February 2009	Farmers could not grow any crop. Shortage of irrigation water for grain-filling stage of rice and for winter cropping
	October 2009–February 2010	Shortage of irrigation water for grain-filling stage of rice and for winter cropping
	October 2010–February 2011	Shortage of irrigation water for grain-filling stage of rice and for winter cropping
Salinity intrusion	October 2008–February 2009	Inability to grow winter crop
	October 2009 – February 2010	Inability to grow winter crop
Hot weather	May, June, and July 2010	Indication of negative effects on rice
	May 2011	Negative effects on human health
Cold spell	January 2008	Massive death of seedlings
	Mid-December 2009–January 2010	Massive death of seedlings which required re-transplanting and delayed spring rice harvest and summer rice planting in 2010
Pest incidences		
Insect damages	Summer rice 2009	About 80% of rice area was damaged
		Stem borer, leaf folder, brown plant hopper, bugs
Disease damages	Summer rice 2009	Hundreds of ha of rice were damaged with 50–90% of yields
		Black-streaked dwarf rice and unidentified disease with symptom of yellow-twisted leaves
Disease damages	Summer 2011	Leaf blight and gray leaf spot

Table 2.4 Rice variety groups, their characteristics, and popularity surveyed in 2011 in Giao Thuy district, Nam Dinh province, Vietnam

Variety group	Rice variety	Characteristics	Popularity[a]
Hybrid	Tap Giao 838, Tap Giao 903	From China, either spring or summer rice, poor taste, higher yield, more response to N fertilizer, hard stem, and resistance to lodging	+++
	CT16	From Vietnam, better taste than Tap Giao, high yield	+
Inbred, non-glutinous (local)	Tam Xoan, Bao Thai, Cuom, Moc Tuyen, Hin	Photoperiod sensitive suited for summer rice; low yield; high tolerance to salinity (Hin)	–
Inbred, non-glutinous (improved)	Q5, Khang Dan	From China, hard rice, and not good taste	–
	Bac Thom 7, Tam Trang	From China, good flavor	+
	BC15, BTR45	From Vietnam, high yield, good taste, resistance to lodging, high response to N fertilizer, sensitive to rice blast (BC15 for spring rice); sensitive to blight (BTR45 for summer rice).	+++
Inbred, glutinous (local)	Nep Cao	Photoperiod sensitive suited for summer rice; tolerance to salinity (Nep Cao)	++
	Nep Cai Hoa Vang		–
Inbred, glutinous (improved)	Nep 87, Nep 97	Photoperiod insensitive suited for both seasons	++

[a](–) no longer growing; (+) less popular; (++) popular; (+++) very popular

2.4.1.4 Case Studies on Rice Production

2.4.1.4.1 Salinity Level of Standing Water in Paddy Fields

Salinity concentration in fields located close to the dyke (e.g., dyke-side paddy in Fig. 2.6) is higher than that in fields further from the dyke (e.g., village-side paddy in Fig. 2.6) during November to February (Fig. 2.7a–d), with the highest value recorded in Giao Thien commune with the value of 0.7% in January 2013. Salinity concentration in the riverside fields in Giao Huong commune (e.g., riverside paddy in Fig. 2.6) between the dyke and river mainstream was much higher, which sharply increased from March to June 2013 (ca. 3%) due to its use for aquaculture.

2.4.1.4.2 Rice Yield and Management

In general, rice yields in spring rice were significantly higher (748 ± 151 g/m^2, $n = 138$) than that in summer rice (417 ± 159 g/m^2, $n = 78$). Rice yield of spring rice ranged from 586 to 857 g m^{-2}, while that of summer rice ranged from 183 to

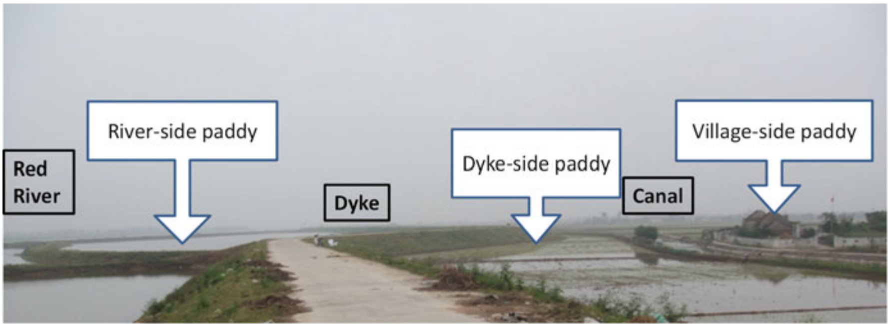

Fig. 2.6 Photograph of land use nearby the dyke of Red River in Giao Huong commune taken from the top of the dyke toward downstream river mouth direction. Main stream of Red River is left-hand side (only partly visible), riverside paddy used as aquaculture (spring) and glutinous rice (summer), dyke, dyke-side paddy, canal, and village-side main paddy on the right-hand side. The canal runs parallel to the dyke as if to prevent possible seepage of saltwater flow from the river toward village-side paddy

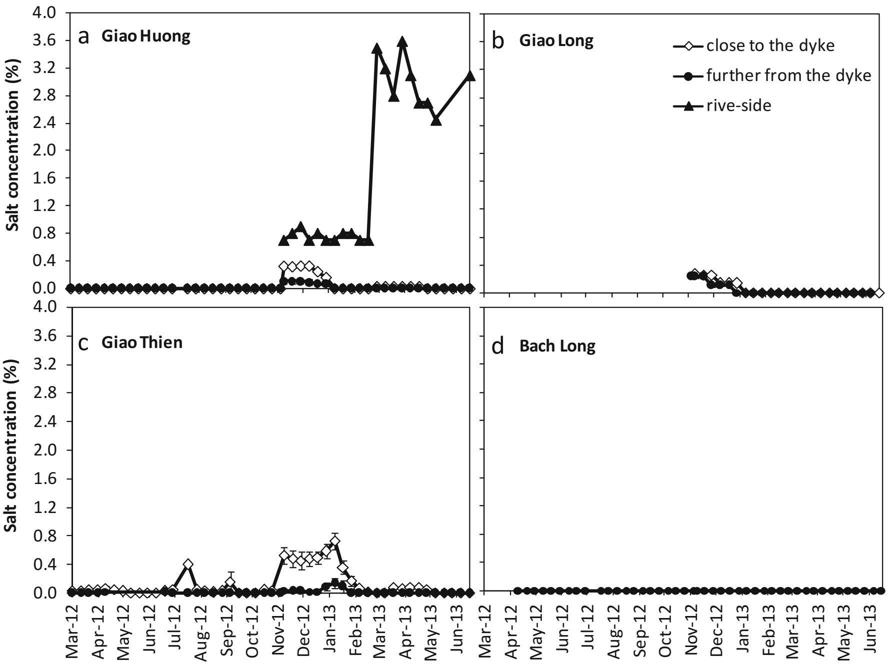

Fig. 2.7 Salt concentration in fields located in different distances from the dyke in the four communes: (**a**) Giao Huong, (**b**) Giao Long, (**c**) Giao Thien, and (**d**) Bach Long (error bars indicate SE)

548 g m^{-2} (Table 2.5). Unfavorable weather for rice production, such as cold spell at flowering time (2011) and flood at harvesting time (2012), and the occurrence of bacterial leaf blight (2012) were noticed in summer rice season. Within the rice season in each year, rice yield in Giao Thien was always significantly lower than that in the other communes. Rice yield in average in fields located far from the dyke (i.e., village-side paddy in Fig. 2.6) was significantly higher than that in fields located close to the dyke (i.e., dyke-side paddy in Fig. 2.6) (667 vs 576 g m^{-2}). This difference was more conspicuous in Giao Thien commune (for all the four rice cropping seasons) and also in Giao Huong commune for summer rice in 2012.

Farmers on average apply N fertilizer with rate of about 200 kg ha^{-1} in both spring and summer rice in all the selected communes. Phosphorus is applied in all the fields, but potassium is not applied in fields close to the dyke in summer rice 2011 and spring rice 2012 in Giao Thien and fields far from the dyke in summer rice 2012 in Bach Long commune (data not shown). Overall average amount of N fertilizer was not different between fields located close to and far from the dyke, but the amount of N in fields close to the dyke in Giao Thien (for summer rice 2011 and spring rice 2012) tends to be lower than that in fields far from the dyke.

2.4.2 Characteristics of Rice Production in Buffer Zone Compared with Outer Zones of Xuan Thuy National Park

2.4.2.1 Statistical Information on Demography and Land

Each of the interviewed five communes has around 2000 households (highest in Giao Xuan, lowest in Giao Thanh) with the populations around 8000 persons (Table 2.6). Average number of persons per household is around 3.4. The very high level of population density is recorded in all the five communes, the lowest in Giao Huong with 764 and the highest in Giao Xuan with 1218 persons/km^2.

Giao Thien had the largest total land areas and Giao Thanh the smallest (Table 2.6). As each commune was located in the delta, percentage of rice-planted area was generally high, with Giao Thanh highest (64%) and Giao Thien lowest (35%). Giao Huong had the largest rice-planted area (527 ha for spring rice 2011). Rice area per household was generally small in buffer zone communes, while non-coastal outer communes (i.e., Giao Huong and Giao Thanh) had higher values.

Giao Thien (319 ha) and Giao Xuan (354 ha) had largest fishery area. Percentage of labor focusing mainly on fishery was high in Giao Xuan (30%), while the other four communes had higher percentage of labor on crop and livestock (more than 80%).

Table 2.5 Rice yield (g m^{-2}) between fields with close and far from the dyke in four communes for four cropping seasons from 2011 summer rice to 2013 spring rice (in total 11 combinations of year, season, and commune) (a). The same rice yield data was arranged as a cross tabulation between season and locations (b)

(a)

Year/season/commune[a] (YSC)	Close to dyke	Far from dyke		Average	
2011 summer GT[b]	497 ± 114 (12)	616 ± 87 (9)	*	548 ± 118 (21)	c
2012 spring GT	533 ± 78 (12)	656 ± 53 (9)	**	586 ± 91 (21)	cd
2012 spring GH	790 ± 53 (9)	829 ± 74 (12)		812 ± 67 (21)	gh
2012 spring BL	820 ± 171 (3)	827 ± 169 (18)		826 ± 165 (21)	gh
2012 summer GT[c]	169 ± 40 (9)	198 ± 7 (9)	†	183 ± 32 (18)	a
2012 summer GH[c]	381 ± 39 (9)	441 ± 42 (12)	**	416 ± 50 (21)	b
2012 summer BL[c]	487 ± 81 (3)	505 ± 95 (15)		502 ± 91 (18)	bc
2013 spring GT	660 ± 172 (12)	824 ± 143 (9)	*	730 ± 177 (21)	ef
2013 spring GH	744 ± 88 (9)	777 ± 67 (9)		761 ± 78 (18)	efg
2013 spring BL	820 ± 53 (3)	864 ± 131 (15)		857 ± 122 (18)	i
2013 spring GL	709 ± 63 (9)	634 ± 160 (9)		672 ± 124 (18)	de
Average	576 ± 211 (90)	667 ± 221 (126)	*	628 ± 221(216)	

(b)

Year/ season	GT		GH		BL		GL		Average
	Close to dyke	Far from dyke	Close to dyke	Far from dyke	Close to dyke	Far from dyke	Close to dyke	Far from dyke	
2011 summer	497	616	–	–	–	–	–	–	548
2012 spring	533	656	790	829	820	827	–	–	741
2012 summer	169	198	381	441	487	505	–	–	369
2013 spring	660	824	744	777	820	864	709	634	754
Average	484	573	638	674	709	738	709	634	

YSC ($P < 0.01$), distance to dyke ($P < 0.05$), and YSC × distance to dyke ($P = 0.07$), according to ANOVA. The 11 average values of YSC followed by the same letter are not significantly different at 1% level. Numbers inside brackets indicate the numbers of samples (replications), and for each of the 11 YSC, T-test was also done between close and far distance fields, showing the significance †$P < 0.1$; *$P < 0.05$; **$P < 0.01$

[a]Commune: *GT* Giao Thien, *GH* Giao Huong, *BL* Bach Long, *GL* Giao Long

[b]Cold spell and irregular rainfall at flowering time in early October leading to high unfilled grain ratio

[c]Bacterial leaf blight; strong typhoon at harvesting time (late October)

Table 2.6 Demography[a], land area, and labor statistics in five communes (Giao Thien and Giao Xuan as buffer zone and Giao Huong, Giao Long, and Giao Thanh as outer zone)

	Buffer zone communes		Outer zone communes		
	Giao Thien	Giao Xuan	Giao Huong	Giao Long	Giao Thanh
Number of households	2500	2747	2030	2643	1781
Population (person)	9486	9232	7320	7672	6085
Population density (people/km ^{2})	804	1218	764	1006	964
Total land area (ha)[b]	1181[b]	758	958	763	631
Rice area (ha)[c]	411	443	527	444	401
Percentage of rice area (%)[c]	35	59	55	58	64
Rice area per household (ha)[c]	0.16	0.16	0.26	0.17	0.23
Fishery area (ha)	319[b]	354[d]	85	74	23
Percentage of labor on fishery (%)	17	30	5	8	2

[a]From the yearly statistical data of Giao Thuy district (2012)
[b]Only land area without including offshore aquaculture area. The 800 ha of the core zone of Xuan Thuy National Park not included
[c]The rice area for spring rice in 2011
[d]Data from 2013. The other data from the statistical data of each commune in 2012

2.4.2.2 Questionnaire for Income Structure

The 200 questionnaires identified that average annual income among the five communes was 57,658,000 VND (about 2700 US$) (Table 2.7), with the proportion of crop, livestock, fishery, and nonagriculture (e.g., employed in big cities such as building workers, masons, motorbike drivers) 22, 25, 30, and 23%, respectively. Giao Thien had the least rice income and highest shrimp culture income, with the high proportion of livestock (e.g., pig) (37%) and nonagriculture (33%) (Fig. 2.8). Giao Xuan had the highest fishery income (i.e., clam culture) and highest nonagricultural income, with their proportion 59 and 16%, respectively. Giao Huong had high rice income and high nonagricultural income, with the proportion of crop and nonagriculture 31 and 43%, respectively. Giao Long had the highest cow income, with the highest proportion of livestock as 43%. Giao Thanh had the highest rice and cash crop incomes, with the proportion of crop income highest (48%). Income from rice production was highest in the two non-coastal outer communes, Giao Thanh and Giao Huong, and the proportion of rice income were higher in the outer zone than buffer zone, with their proportion 31 and 12%, respectively. Buffer zone communes tended to have more diversified income sources such as non-rice cash crops (e.g., cabbage, kohlrabi, lettuce, chili), fruits, livestock (e.g., pig, chicken, duck), fishery (e.g., shrimp, clam), and nonagriculture. The order of the total annual in the questionnaire (i.e., highest in Giao Xuan, followed by Giao Huong and Giao Thien, and then by Giao Long, and least in Giao Thanh) was also supported by the statistical data from the district in 2012.

Table 2.7 Average income of household per year (10^3 VND) from crop, livestock, fishery, and nonagriculture sources in five communes (Giao Thien and Giao Xuan as buffer zone communes and Giao Huong, Giao Long, and Giao Thanh as outer zone communes) in 2011

Income sources	Buffer zone communes		Outer zone communes			Average ($n = 200$)	p-value[a]
	Giao Thien ($n = 40$)	Giao Xuan ($n = 39$)	Giao Huong ($n = 40$)	Giao Long ($n = 41$)	Giao Thanh ($n = 40$)		
Crop							
Rice	7826c (1023)	12,028ab (1115)	13,315a (1319)	8699bc (1014)	15,186a (1814)	13,411	0.000
Cash crops	1213a (411)	1170ab (397)	195b (142)	101b (70)	1599a (435)	536	0.002
Fruits	243 (177)	402 (204)	0 (0)	24 (24)	180 (151)	170	0.223
Subtotal	9281b (1235)	13,600a (1180)	13,510a (1319)	8824b (1029)	16,965a (1921)	12,436	0.000
Livestock							
Pig	11,520 (3581)	12,057 (2824)	8220 (4027)	9959 (2976)	7625 (3081)	9876	0.849
Cow	0b (0)	385b (385)	0b (0)	1648a (575)	0b (0)	407	0.000
Chicken	4025 (1873)	3226 (1409)	1630 (614)	5183 (2232)	1965 (625)	3206	0.434
Duck	350b (188)	1538a (856)	23b (23)	244b (244)	0b (0)	431	0.044
Subtotal	15,985 (4447)	17,872 (4220)	10,298 (4046)	17,045 (4105)	9590 (3185)	14,158	0.440
Fishery							
Clams culture	500b (349)	67,590 a (45,572)	0b (0)	1220b (1500)	0b (0)	13,862	0.066
Shrimp culture	1500a (698)	0b (0)	450b (450)	0b (0)	0b (0)	390	0.018
Crab culture	500 (240)	0 (0)	150 (150)	1512 (1237)	0 (0)	432	0.304
Fish culture	350 (217)	1923 (1359)	550 (379)	1463 (1238)	50 (50)	867	0.481
Shrimp capture	125 (125)	2205 (1550)	0 (0)	1463 (1463)	0 (0)	759	0.345
Others capture	425 (301)	3026 (2593)	0 (0)	3620 (1558)	0 (0)	1414	0.127
Subtotal	3400b (1171)	74,744a (48,040)	1,150b (819)	9,278b (3105)	50b (50)	17,724	0.061

(continued)

Table 2.7 (continued)

Income sources	Buffer zone communes		Outer zone communes			Average ($n = 200$)	p-value[a]
	Giao Thien ($n = 40$)	Giao Xuan ($n = 39$)	Giao Huong ($n = 40$)	Giao Long ($n = 41$)	Giao Thanh ($n = 40$)		
Nonagriculture							
	14,394abc (6138)	20,681a (4130)	18,563ab (4600)	4482c (1591)	8,581bc (3476)	13,340	0.04
Total income	43,060b (8884)	126,897a (47,054)	43,520b (6505)	39,629b (5547)	35,186b (5677)	57,658	0.013

[a]Significant differences within five communes ($p < 0.05$)

2.4.2.3 Questionnaire for Fertilizer and Pesticide Inputs

The 200 questionnaires also identified that the five communes had very high nitrogen fertilizer (urea) application rate in both spring and summer rice (Table 2.8), with 476 and 438 kg/ha, respectively (nitrogen element 219 and 201 kg/ha). Phosphorus fertilizer (fused magnesium phosphate) was also heavily applied, while manure application, which had been used much more before 2000 according to the interview, was little in 2011. In spring rice 2011, the average urea fertilizer application rate was higher in buffer zone communes (545 kg/ha) than outer communes (430 kg/ha). Phosphorus fertilizer was applied more in the two non-coastal outer communes (Giao Huong, Giao Thanh) than the three coastal communes, because of more acidic soil that would require higher phosphorus for better plant stands in Giao Huong and Giao Thanh (according to the farmers' perception). Similar trends of nitrogen and phosphorus fertilizer application rates were observed in summer rice, in which the average urea fertilizer application rate was higher in buffer zone communes (483 kg/ha) than outer communes (409 kg/ha).

Numbers of pesticide application in 2006 (2.8 and 2.9 in spring and summer rice on average of the five communes, respectively) increased by 2011 (4.1 and 3.7 in spring and summer rice, respectively) (Table 2.9). In 2006, the numbers of application were most frequent in Giao Xuan, followed by Giao Thien and Giao Thanh. In 2011, the application time was not different in spring rice among five communes, and Giao Huong was higher than Giao Xuan and Giao Long in summer rice.

2.5 Discussion

2.5.1 Indication of Climate Change and Saltwater Intrusion in Red River Delta

Our study alarmed clear rising temperature (0.3 and 0.1 °C per decade for annual average daily maximum and minimum temperature) from 1961 to 2010 at Nam Dinh city, the provincial capital located in Red River Delta, and increasing

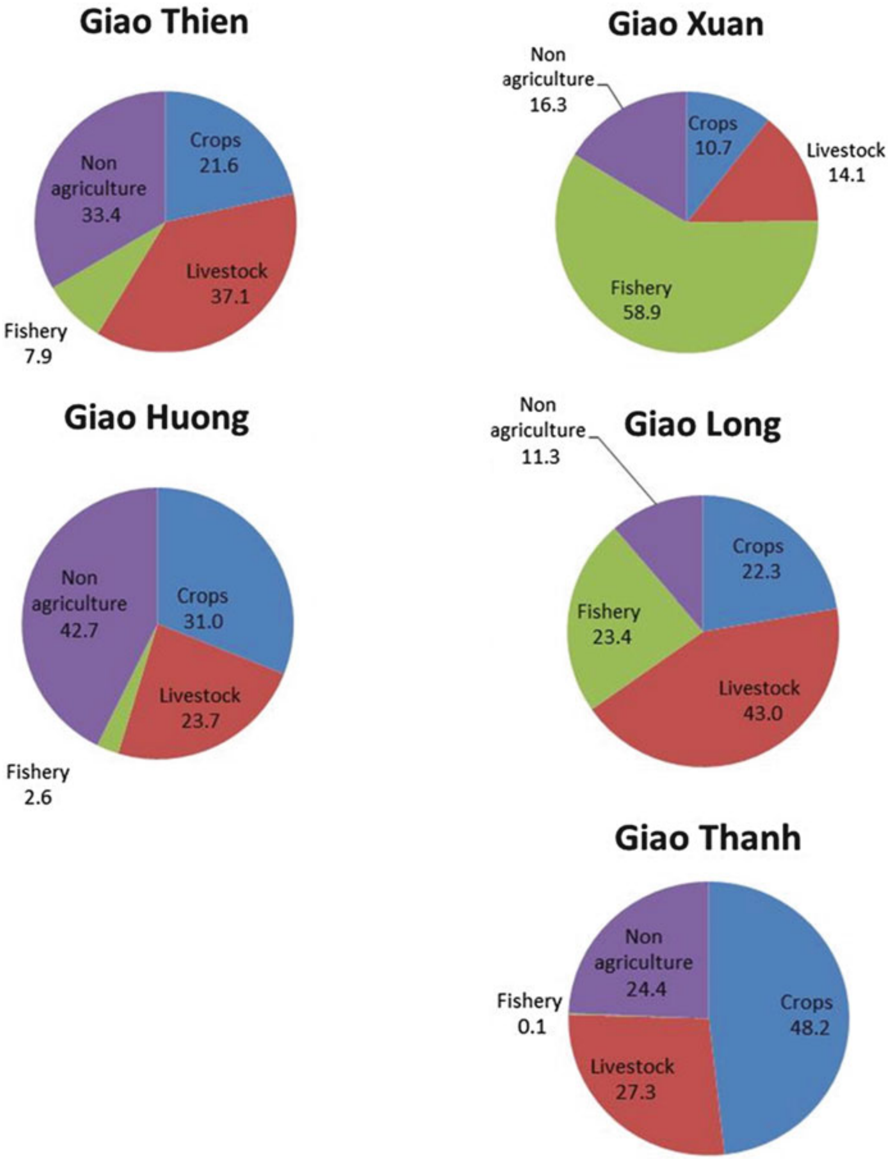

Fig. 2.8 Income structure from crop, livestock, fishery, and nonagriculture sources in five communes (Giao Thien and Giao Xuan as buffer zone communes and Giao Huong, Giao Long, and Giao Thanh as outer zone communes) in 2011 in Giao Thuy district, Vietnam

Table 2.8 Application rates of fertilizers (kg/ha/season) for spring and summer rice in five communes (Giao Thien and Giao Xuan as buffer zone communes and Giao Huong, Giao Long, and Giao Thanh as outer zone communes) in 2011 (mean, (SE))

Cropping seasons	Fertilizers	Buffer zone communes		Outer zone communes			p-value[c]
		Giao Thien (n = 40)	Giao Xuan (n = 39)	Giao Huong (n = 40)	Giao Long (n = 41)	Giao Thanh (n = 40)	
Spring rice	Nitrogen fertilizer[a]	493 bc	596 a	432 c	529 ab	328 d	0.000
		(28)	(39)	(34)	(38)	(16)	
	Phosphorus fertilizer[b]	174 b	157 b	370 a	105 b	371 a	0.000
		(38)	(38)	(43)	(33)	(38)	
	Manure fertilizer	0 b	0 b	125 a	0 b	17 b	0.003
		(0)	(0)	(57)	(0)	(17)	
Summer rice	Nitrogen fertilizer[a]	470 ab	495 a	409 b	503 a	314 c	0.000
		(31)	(37)	(27)	(42)	(14)	
	Phosphorus fertilizer[b]	238 bc	135 cd	352 ab	111 d	402 a	0.000
		(50)	(34)	(46)	(35)	(39)	
	Manure fertilizer	0 a	71 a	208 a	339 a	156 a	0.538
		(0)	(71)	(208)	(199)	(140)	

[a]Urea (46% N).[b]Fused phosphorus fertilizer (15–17% P_2O_5).[c]Significant differences within five communes ($p < 0.05$)
Different alphabet characters after mean indicate significant differences between communes

Table 2.9 Number of times of pesticide application (mean, (SE)) for spring and summer rice in 2006 and 2011 in five communes (Giao Thien and Giao Xuan as buffer zone communes and Giao Huong, Giao Long, and Giao Thanh as outer zone communes)

Cropping seasons	Year	Buffer zone communes		Outer zone communes			p-value[a]
		Giao Thien (n = 40)	Giao Xuan (n = 39)	Giao Huong (n = 40)	Giao Long (n = 41)	Giao Thanh (n = 40)	
Spring rice	2006	2.8 b	3.3 a	2.5 b	2.6 b	2.7 b	0.012
		(0.1)	(0.2)	(0.1)	(0.2)	(0.1)	
	2011	4.0 a	4.3 a	4.0 a	3.9 a	4.3 a	0.709
		(0.2)	(0.3)	(0.2)	(0.2)	(0.2)	
Summer rice	2006	2.8 b	3.4 a	2.7 b	2.6 b	2.9 ab	0.016
		(0.1)	(0.2)	(0.2)	(0.2)	(0.2)	
	2011	3.7 ab	3.3 b	4.1 a	3.3 b	3.9 ab	0.040
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	

[a]Significant differences within five communes ($p < 0.05$)
Different alphabet characters after mean indicate significant differences between communes

magnitude of seawater intrusion toward the water gate 18 km from the Ba Lat estuary of Red River mouth. These were considered as local indications of environmental changes over decades which are at least partly associated with the effects of climate changes in Vietnam. The Ministry of Natural Resources and

Environment, Vietnam, also reported the rise of annual average temperature at Hanoi and Ho Chi Min city by 0.8 and 0.6 °C, respectively, from the 1930s to 1990s (MONRE 2009). Some remarks were needed however; the analyzed climate data in this study was collected in an urban station at Nam Dinh city, the provincial capital of Nam Dinh province, and temperature rise due to urbanization may have been confounded (Nelson et al. 2009). The station is about 30 km inland from the target study site of the coastal zone of Giao Thuy district, and there may have been differences between the inland and the coastal area, for example, in rainfall incidence. We did not find a significant changing trend of annual and seasonal amounts of rainfall from 1961 to 2010, as was the previous report (MONRE 2009), but the reality of the coastal zone may be different. The rainfall in Giao Thien commune measured in 2011–2013 were more than 1900 mm, 300 mm more than the annual average of the collected data (A. Kamoshita, personal communication), and it is indicated that typhoon with higher intensity hit Vietnam more frequently in recent years (MONRE 2009).

The increasing trend and threats of seawater intrusion (Fig. 2.3) resulted from the rising of the sea level in combination with decrease of water level in Red River from December to March due to reducing rainfall and more water uses in upstream in Vietnam and China (i.e., hydropower station) (1 and 2 in Fig. 2.9). Global mean sea level has risen by 0.19 m over the period 1901–2010, with higher mean rate of 3.2 mm year^{-1} between 1993 and 2010 than 1.7 mm year^{-1} between 1901 and 2010 (Rhein et al. 2013). Sea level rise rate in Vietnamese coastal area was 3 mm year^{-1} from 1993 to 2008 (MONRE 2009), and minimum water level of the Red River has dramatically declined to its lowest level in the past 100 years (e.g., 255 cm in 2000 vs 66 cm in 2009) (Giang et al. 2013). Our analysis result of the monthly dynamic pattern of salt concentration (2003–2012) in dry season from December to May agreed with that of Ca (1996) during the period of 1963–1992, but the salinity level in our study (1% in Con Nhat with distance of 13.5 km from the Ba Lat river mouth) almost doubled the previous study (0.6% in Ba Lat station with distance of 1.8 km), indicating acceleration of seawater intrusion and greater vulnerability of rice production. Thanh et al. (2004) indicated that isohaline of 0.1% salinity has moved landward by 4–10 km per decade, with the current region of seawater intrusion of Red River about 30–50 km from the river mouth. Extreme weather such as heavy storm would also become greater threats of seawater intrusion (3 in Fig. 2.9). A leakage of salt water through dyke has been also recognized by farmers as a threat of seawater intrusion to paddy fields nearby dykes (4 in Fig. 2.9).

2.5.2 *Vulnerability of Rice Production*

Our measurement results showed that salt concentration of standing water in the paddy fields in Giao Thuy was generally lower than upper limit for agricultural production (0.4%) during rice-growing season (February to November). The exception was the fields located adjacent to the river (riverside paddy in Figs. 2.6 and 2.7a) which recorded much higher salt concentration for use for aquaculture during

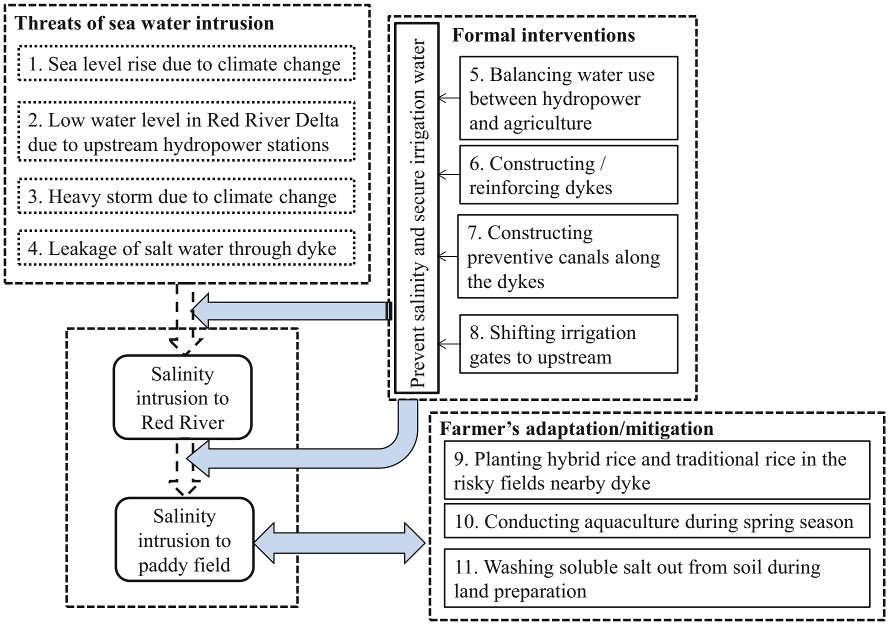

Fig. 2.9 Formal interventions and farmers' adaptive/mitigating to threats of seawater intrusion in Red River Delta, Giao Thuy district, Vietnam

spring rice season 2013. This result indicated irrigation water management to exclude the river water of high levels of salts was generally successful for rice production in this area.

However, there were possibly indirect effects of increasing level of seawater intrusion and decreasing irrigation period at the downstream intake gates nearby Red River mouth. Firstly, Giao Thien commune had to change the intake gate from nearby downstream to further upstream, which means irrigation water to the selected fields in Giao Thien has to come through the longest distance of the canals. This may have caused a missing of the best timely management practices and the lower level of yield in the surveyed fields in Giao Thien (e.g., spring rice in 2012, close fields of spring rice in 2013). In addition, Giao Thien is located in the most downstream, and hence flood damages by typhoon (e.g., summer rice in 2012) could have been most serious.

Secondly, our results showed significantly lower yield in fields close to dyke/salt fields than that in far fields; salinity level in standing water was higher in the close fields, but its level was still within the range of normal growth for rice and hence not considered as a primary factor. Overall NPK fertilizer inputs were not different between close and far distance fields from dyke, but for specific situations such as summer rice in 2012 in Giao Thien, farmers input less amount of N to the close fields from dyke, which may indicate a greater risk of production failure in the close fields from dyke.

The "salinity-affected area" by commune leaders in Giao Thuy (Table 2.1) may have contained both direct and indirect influences of salinity. They may have included relatively low productive fields, due to not only salinity but also flood or poor drainage. The 78 ha of land that located adjacent to the river outside of the dyke in Giao Huong (i.e., flood plain space between river water and dyke) may have been included, as these plain had high salt concentration in spring time and prone to flood from the river water. Sea sluice gate number 9 was repaired in 2010, which has improved the protection system against seawater intrusion in the coastal area of Giao Long and Giao Xuan; during the interview for "salinity-affected area" in Table 2.1, the commune chiefs in Giao Long and Giao Xuan may have mistakenly included the vulnerable area nearby the sea sluice gate number 9 which had suffered from damages derived from high tide and seawater intrusion in the past before 2010. The interview and the case field study of rice production indicated the presence of incidence of climate and pest hazards, highlighting the damages such as in 2005 and 2009 (Fig. 2.4) and 2012 (Table 2.5) and showing the vulnerability of rice production.

2.5.3 Improvement of Resilience of Rice Production

In order to improve resilience of rice production to flooding, the government had strengthened physical structure of the dyke and the gates of the canals (6 in Fig. 2.9). This is considered to have improved resilience to seawater intrusion too. There have been other formal interventions by government and irrigation companies such as construction of a small canal outside of the dyke to protect village-side paddy area from leakage of salt water (7 in Figs. 2.6 and 2.9) and closure of a downstream irrigation gate where salt concentration in the river was over the limit for agricultural production and shift to upstream gates for irrigation intakes (8 in Fig. 2.9). Balancing of the water use of Red River between hydropower and agricultural sectors (5 in Fig. 2.9) is also an important role of the government as the higher flow rate of river will push back the intruding seawater (as was the case of Mekong delta (Le et al. 2007)). The formal interventions work to prevent salinity intrusion to Red River and individual paddy fields and to secure irrigation water.

On farm level, soluble salts invading into paddy fields can be washed out from soil during land preparation (i.e., January to February for spring rice) as a mitigation method (11 in Fig. 2.9), which is only possible if there is enough irrigation water and good drainage system. Planting hybrid rice varieties in the poor-drained fields nearby the dyke is an adaptive measure by farmers, as the hybrid vigor can minimize the reduction arising from the marginal conditions (9 in Fig. 2.9). Another adaptation in the riverside paddy fields (Fig. 2.6) is to adopt a land use of aquaculture (spring)–rice (summer) system (10 in Fig. 2.9); aquaculture is conducted during spring when the level of seawater intrusion is high and salt concentration of river tended to be higher (Fig. 2.7a) (Nguyen et al. 2015) and a traditional glutinous rice variety (i.e., Nep Cao) is cultivated during summer when the risk of salinity is lower but flooding could occur (9 in Fig. 2.9). Nep Cao variety has higher plant height, larger straw growth, and photoperiod sensitivity, which are considered as suited plant characters in the flood-prone riverside paddy. A local level farmer adaptation in the choice of varieties should be well understood by provincial agricultural department. In addition, desirable genetic and physiological architecture for salinity tolerance may be created by searching and incorporating genes from traditional varieties adapted in saline tidal areas in order to develop adaptive and superior varieties (e.g., higher yield and higher quality with salinity tolerance). Figure 2.9 summarizes both formal interventions by government and by irrigation companies and adaptive/mitigation measures by farmers which have been practiced to cope with the threats of seawater intrusion and to increase resilience of the rice production in Red River Delta. Resilience can be improved by mitigation policy of climate change, hydrological management of the river, and agricultural water management but also by farm-level mitigation and adaptation measures.

2.5.4 Characters of Agriculture and Rice Production in Buffer Zone

From the case analysis of two buffer zone communes and three outer zone communes around Xuan Thuy National Park, the following indicative differences between the two groups were identified: buffer zone communes were unique for their utilization of marine resources (i.e., fishery) and for farm diversification (e.g., fruits, duck, mushroom culture, medicinal plants cultivation (*Styphnolobium japonicum* (L), called Hoa Hoe in Vietnamese). Outer zone communes had larger total and per household rice lands and received larger percentages/amounts of income from rice. The greater opportunity for farm diversification in buffer zone communes would contribute to higher resilience to long-term changing environmental conditions as predicted to be caused by climate change (FAO 2001, 2008; IPCC 2013); if the salinity level of the region should further increase in 50 years in the future due to sea level rise, transforming from rice to aquaculture or to other crops more adapted to saline conditions would be more effective choices for continuing economically viable agriculture in this region.

Our study also highlighted that rice production intensity (i.e., N fertilizer application rate, pesticide application numbers) in buffer zone communes was similarly high as was the case in outer zone communes by household survey. More than 200 kg/ha per season of nitrogen element were inputted. This amount was surprisingly high compared with average nitrogen application rate in developed countries (e.g., 66 kg/ha in case of Japan (Mishima and Kohyama 2010)). China also had similarly high nitrogen application rate per season as in this study, but commonly with single cropping per year due to temperate climate, while the study site in Red River Delta had two rice cropping seasons per year, amounting to annually ca. 400 kg/ha of nitrogen input. We thought that the fertilizer application rate would have been to some extent smaller in buffer zone communes than the outer zone communes, but our study showed that nitrogen input was similarly high and so with the pesticide application times. This result indicates the current dominant orientation of the farmers to the higher production of rice and little awareness of necessity of reducing agricultural inputs for environmental conservation. Government initiatives to properly control agricultural inputs will be needed as discussed in Sect. 2.5.5.1. How the applied N fertilizers and pesticides will move in the coastal environments is not known. It may cause eutrophication of water systems, such as canal or coast (Thanh et al. 2004), and biological concentration of synthesized substances. Such scientific investigation is needed.

2.5.5 Rural Development for Improved Resilience Around Xuan Thuy National Park

As most productive rice-growing rural area bordered with Xuan Thuy National Park in Vietnam, finding global (i.e., export to foreign countries) and/or urban (e.g., Nam Dinh city, Hanoi) market and managing natural resources are essential for rural development of Giao Thuy district which would improve sustainability and resilience. From the rural community, agro-natural values are provided to urban and global communities (e.g., consumer groups in Nam Dinh and Hanoi cities in Vietnam and in foreign countries importing those values), such as agricultural products cultivated by environment-friendly and economic methods and met with standard high quality (i.e., certificate system), biodiversity in the coastal ecosystems and cultural heritage of the national park, and so on (Fig. 2.10). From the urban and/or global communities, agro-natural values in the rural community are understood, price of the agricultural products is paid, and tourism is promoted. The close partnership between rural and urban/global communities would be beneficial for rural development and increasing resilience to any unexpected incidences such as climate hazards (e.g., Table 2.3) and longer-term climate change (e.g., Figs. 2.2 and 2.3) and large fluctuation of price of agricultural products. One example is GLOBAL GAP certification system of clam in Giao Xuan commune approved in 2004 to export to Europe (Oanh 2012; VietBao 2005), as this certificate system could better protect farmers from the recent price drop of clam from 25,000 VND per kg to 9000–11,000 VND per kg (vietnamseafoodnews.com/Vietnam-the-north-develops-the-brand-of-environmental-friendly-clam/).

Enhancement of local market and proper natural resource management are also important (Fig. 2.10). Various local agricultural products (e.g., clam, shrimp, mushroom, fruits, duck) are brought to the local market, and the price of these products increases income of local farmers. Awareness is raised for the value of environmental protection and the importance of reducing emission from

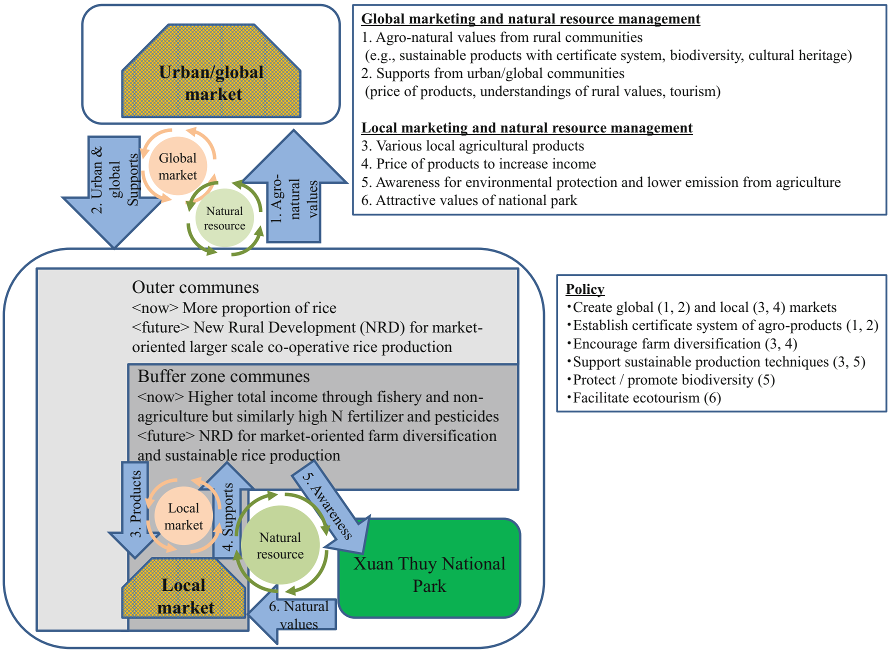

Fig. 2.10 Schematic rural development (in both buffer zone and outer communes) around Xuan Thuy National Park. Market development (local, urban/global) and natural resource management were key cycles for development which need government policy implementation such as New Rural Development (NRD). In global marketing cycles, (1) agro-rural and natural values of the target rural area, such as agricultural sustainable products, biodiversity, and cultural heritage, were provided to urban/global markets, while (2) in return urban/global communities provided supports such as price of products, understandings of rural area, and ecotourism to the rural area. In local marketing and management cycles, (3) various local agricultural products were brought from the buffer zones and outer communes to the local market (4) which in return provided income for livelihood. (5) Raised awareness for environmental conservation of national park and for lower emission from agricultural production in buffer zone communes would (6) increase attraction values of the national park, which can activate the local market further. New Rural Development policy can strengthen each component of the cycles

agriculture, which would protect and enhance the attractive values of nature in the national park. As the national park would get renovated and become more widely known to attract nonlocal people of ordinary citizens in Vietnam and for amateurs and professionals of biology/biodiversity, external visitors for ecotourism would increase to create larger local market of Giao Thuy district and Nam Dinh province (e.g., restaurants for external visitors).

Political leadership was crucial for improving resilience by facilitating economic development in rural areas and by conserving environment and promoting biodiversity, as was seen in the significant recent legal document of the Decision No. 800/QDTTg on approving the national target program on building a new countryside during 2010–2020 in Vietnam (Prime Minister Office 2010). The general objectives of this decision were to build more economic viable countryside, to associate agriculture with business, to promote rural community's culture and democracy, to protect environment, and to empower people's holistic lives, which is termed as New Rural Development (NRD). NRD was to be implemented in all over 9071 communes in Vietnam from 2010 to 2020, including those around Xuan Thuy National Park in Red River Delta. The following political supports by government should be helpful as NRD in Giao Thuy: (1) creating both global and local markets where rural agricultural products are to be delivered, (2) establishing certificate system of agro-products, (3) encouraging farm diversification, (4) supporting sustainable production techniques, (5) protecting/promoting biodiversity, and (6) facilitating ecotourism (Fig. 2.10).

Within Giao Thuy district, as has been discussed in the previous Sect. 2.5.4, buffer zone and outer zone around Xuan Thuy National Park have different characteristics in agricultural production, which should be developed in zone-specific manner as discussed below.

2.5.5.1 Prospects for Buffer Zone: Lower Agrochemical Inputs for Rice and Diversification

Buffer zone communes have higher income from more diversified production systems including fishery, non-rice crops, livestock, and nonagriculture (Table 2.7), but little attention has been so far paid for avoiding overloading of fertilizers and/or pesticides (Tables 2.8 and 2.9) and for improving their utilization efficiency. It would be important to emphasize that the NRD should guide development and dissemination of sustainable rice production methods of nutrient and pest management in buffer zone communes for environmental conservation and enhancement of biodiversity of the national park (cf. Hong et al. 2007a, b). Technical innovation to improve fertilizer use efficiency, including application methods and variety improvement (Peng et al. 1996; Xie et al. 2007), would be needed, as well as the concept of low-input sustainable agriculture. Heong et al. (2013) showed many examples of integrated pest management (IPM) that chemical spraying time could be reduced for the control of rice leaf folder without sacrificing yield.

The NRD should also consider establishing certificate system such as good agricultural practice (GAP), as this will enable to encourage adopting cultivation methods with higher awareness to environment conservation, with less input and higher utilization efficiency of agrochemicals. Further, it is theoretically possible to connect rice production with the local conservation of biodiversity, as is the case of Konotori brand rice in Japan (i.e., rice produced in biodiversity rich fields where cranes habituate and sold with higher price (Kim et al. 2011; Ohnishi 2012)). If this system should be applied to the buffer zone, a new brand such as "Xuan Thuy rice" would be developed as rice produced in buffer zone of highly biodiverse Xuan Thuy National Park, but the formulation of good consumer groups in urban and global communities (e.g., Vietnam, foreign countries) to buy and eat such rice would be prerequisite.

2.5.5.2 Prospects for Outer Zone: Market-Oriented Larger-Scale Rice Production

In outer zone communes, rice production had greater proportion in agriculture, but unit farm scale is still small compared with other Asian countries (Tables 2.6 and 2.7). The land consolidation and larger-scale uniform rice production can improve productivity and open the greater chance for marketing rice, as has been recently initiated in 2013 in the nearby commune (i.e., Giao Ha) with 40% of the production from 91 ha of the consolidated rice fields for sale through the contract with the local rice company. Although careful assessment is needed including social conditions of the local community, it would be a possible option for NRD to facilitate development of market-oriented larger-scale cooperative rice production; marketable rice varieties with high consumer demands (e.g., taste, grain quality) should be uniformly and cooperatively cultivated in larger areas (ca. 10–20 ha) to attain high yield with efficient use of moderate amounts of resource inputs. Giao Huong and Giao Thanh had developed a strategy for farmers to grow high-quality and high-yield rice varieties such as BC15 and improved Tam varieties (e.g., Table 2.4), through collaboration with Agricultural Extension Station and Plant Protection Station of Giao Thuy district.

In global rice sector, International Rice Research Institute (IRRI) and United Nations Environmental Programme (UNEP) co-convened "sustainable rice platform" (SRP) from 2011 to improve resource use efficiency and sustainability in rice cultivation and to promote rice marketing; SRP had certain criteria such as to keep the environment healthy, facilitate safer working conditions, and generate higher incomes to overcome poverty and improve food security (FarEastAgriculture 2012). Rice farmers in outer zone may need to take SRP into account if they attempt to bring their quality rice to global market.

Acknowledgment This study was supported by the Environmental Research and Technology Development Fund (E-1101) of the Ministry of the Environment, Japan. We thank the farmers, the irrigation company, and the staff in Giao Thuy district for their cooperation in interviews and field data collection. Research was designed and the manuscript was written by AK; the survey and analysis of climatic hazard section (i.e., Sect. 2.4.1) and buffer zone section (i.e., Sect. 2.4.2) were done by NTBY and DTHV. We appreciate useful discussion with Prof. H. Kurokura and H. Matsuda, University of Tokyo.

References

Ca VT (1996) Salinity intrusion in the Red River Delta. Seminar on environment and development in Vietnam, National Centre for Development Studies, Australian National University, Australia

Cach NV (2005) Report on present situation of Xuan Thuy National Park, Giao Thuy (in Vietnamese)

Dao PTA, Hong PN, Tuan LX, Phuong TM, Tho NH (2007) Xuan Thuy National Park: socio-economic. MERC-MCD, Hanoi, p 26

Ebregt A, Greve PD (2000) Buffer zones and their management: policy and best practices for terrestrial ecosystems in developing countries. International Agriculture Centre, Wageningen, pp 11–13

Fareastagriculture (2012) IRRI launches Sustainable Rice Platform initiative [Online]. Available: http://www.fareasternagriculture.com/crops/food-commodity/irri-launches-sustainable-rice-platform-initiative. Accessed 4 Apr 2014

Food and Agriculture Organization of the United Nations (FAO) (2001) Integrated agriculture-aquaculture: a primer FAO fisheries technical paper T407, FAO, Rome, p 149

Food and Agriculture Organization of the United Nations (FAO) (2008) Climate change and food security: a framework document. Interdepartmental working group on climate change, FAO, Rome, p 93

General Statics Office (GSO) (2012) Statistical handbook of Vietnam. Hanoi, Vietnam

Giang PQ, Toshiki K, Kunikane S, Sakata M (2013) Climate change challenges transboundary water resources management: drawing from the case of Vietnam. The 3rd conference on chemical, biological and environmental sciences (ICCEBS'2013). Kuala Lumpur, pp 48-52

Giao Thuy District People's Committee (DPC) (2010) Statistic year book, Giao Thuy district. Nam Dinh province, Vietnam

Hanh TTP, Kurukawa M (2007) Impact of sea level rise on coastal zone of Vietnam. Bull College Sci Univ Ryukyus 84:45–59

Heong KL, Wong L, Reyes JHDL (2013) Addressing plant hopper threats to Asian rice farming and food security: fixing insecticide misuse. ADB sustainable development working paper series, vol 27. Asian Development Bank, Manila, p 13

Hong PDV, Tu ND, Cach NV, Binh LT (2007a) Xuan Thuy National Park: policy brief. VEPA-MCD, Hanoi, p 26

Hong PN, Tuan LX, Dao PTA (2007b) Xuan Thuy National Park: biodiversity. MERC-MCD, Hanoi, p 42

IPCC (2013) The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds). Cambridge University Press, Cambridge, p 1533

Kim JO, Lee SH, Jang KS (2011) Efforts to improve biodiversity in paddy field ecosystem of South Korea. Reintroduction 1:25–30

Kotera A, Sakamoto T, Nguyen DK, Yokozawa M (2008) Regional consequences of seawater intrusion on rice productivity and land use in coastal area in Mekong River Delta. JARQ 42:267–274

Le TVH, Nguyen HN, Wolanski E, Tran TC, Haruyama S (2007) The combined impact on the flooding in Vietnam's Mekong River delta of local man-made structures, sea level rise, and dams upstream in the river catchment. Estuar Coast Shelf Sci 71:110–116

Ministry of Natural Resources and Environmental (MONRE) (2009) Climate change, sea level rise scenarios for Vietnam. Available via DIALOG. http://www.preventionweb.net/files/11348_ClimateChangeSeaLevelScenariosforVi.pdf. Accessed 15 Jan 2014

Minot N, Goletti G (2000) Rice market liberalization and poverty in Vietnam. International Food Policy Research Institute, Washington, DC, p 114

Mishima S, Kohyama K (2010) The database and the methodologies to estimate recent trend of nitrogen (N) and phosphate (P) flows and residual N and P in Japanese national prefectural scales and examples their application. Bulletin of National Institute for Agro-Environmental Sciences 27:117-139 (Japanese with English summary)

Nelson KC, Palmer MA, Pizzuto JE, Moglen GE, Angermeier PL, Hilderbrand RH, Dettinger M, Hayhoe K (2009) Forecasting the combined effects of urbanization and climate change on stream ecosystems: from impacts to management options. J Appl Ecol 46:154–163

Nguyen YTB, Kamoshita A, Dinh VTH, Matsuda H, Kurokura H (2017) Salinity intrusion and rice production in Red River Delta under changing climate conditions. Paddy Water Environ 15:37–48

Oanh ĐN (2012) Nghề nuôi Ngao ở Giao Thủy [Online]. Available: http://giaothuy.namdinh.gov.vn/Home/Tinhoatdong/2012/233/Nghe-nuoi-ngao-o-Giao-Thuy.aspx. Accessed 7 Nov 2013

Ohnishi N (2012) Rural development with animal conservation using the local farming practices in Japan. J Agrofor Environ 6:65–68

Peng S, Garcia FV, Laza RC, Sanico AL, Visperas RM, Cassman KG (1996) Increased N-use efficiency using a chlorophyll meter on high-yielding irrigated rice. Field Crop Res 47:243–252

Prime Minister Office (2010) Decision no. 800/QD-TTg on t approving the national target program on building a new countryside during 2010–2020 [Online]

Rhein M, Rintoul SR, Aoki S, Campos E, Chambers D, Feely RA, Gulev S, Johnson GC, Josey SA, Kostianoy A, Mauritzen C, Roemmich D, Talley LD, Wang F (2013) Observations: ocean. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of working group I to the Fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Thai HT, Van TT (2011) Assessment of climate change impacts on salinity intrusion in Hong-Thai Binh and Dong Nai river basins. VNU J Earth Sci 27:54–61

Thanh TD, Saito Y, Huy DV, Nguyen VL, Ta TKO, Tateishi M (2004) Regimes of human and climate impacts on coastal changes in Vietnam. Reg Environ Chang 4:49–62. https://doi.org/10.1007/s10113-003-0062-7

Tuong TP, Kam SP, Hoanh CT, Dung LC, Khiem NT, Barr J, Ben DC (2003) Impact of seawater intrusion control on the environment, land use and household incomes in a coastal area. Paddy Water Environ 1:65–73

Vietbao (2005) Tỷ phú Ngao [Online]. Available: http://vietbao.vn/The-gioi-tre/Ti-phu-ngao/40095501/275/. Accessed 7 Nov 2013

Vu MC, Bui DD (2006) Assessment of saline water intrusion into estuaries of Red-Thai binh River during dry season having considered water released from upper reservoirs and tidal fluctuation. Vietnam - Japan Estuary Workshop, Hanoi, pp 12–19

Wassmann R, Hien NX, Hoanh CT, Tuong TP (2004) Sea level rise affecting the Vietnamese Mekong Delta: water elevation in the flood season and implications for rice production. Clim Chang 66:89–107

Xie WX, Wang GH, Zhang QC, Guo HC (2007) Effects of nitrogen fertilization strategies on nitrogen use efficiency in physiology, recovery, and agronomy and redistribution of dry matter accumulation and nitrogen accumulation in two typical rice cultivars in Zhejiang. China J Zhejang Univ Sci B 8:208–216

Young KB, Wailes EJ, Cramer GL, Khiem NT (2002) Vietnam's rice economy: developments and prospects. University of Arkansas Agricultural Experiment Station Research Bulletins, 968

Chapter 3
Farmers' Behavior for Introducing Livestock to Respond to External Shocks

Hirotaka Matsuda, Yuka Ogata, Akira Takagi, and Hisashi Kurokura

Abstract The purpose of this chapter is to reveal factors to introduce or raise livestock by farmers to respond to external shocks such as rapid economic growth with globalization and extreme weather events. Risk behaviors of farmers, social networks, and credit constraints are considered the main factors in this chapter. The target research area is the northern part of Vietnam around the Red River Delta. The villagers have a traditional home garden system, the so-called VAC, comprising trees for fruit, ponds for aquaculture, and livestock with high resilience. Because of the intrusion of the market economy, the traditional system is collapsing, although livestock can be considered a method to make smooth consumption in response to shocks. This chapter indicates that farmers in the targeted communities are coping with the intrusion of the market economy as an external shock. Raising livestock to generate a profit in the market has gained greater focus. Larger inputs for livestock may have caused environmental degradation and must be examined. Raising livestock is one of the major methods to enhance the resilience of households through smoothing consumption. However, it is probably causing other unexpected problems in the area because of the loss of the stability of the traditional VAC system.

Keywords VAC system · Traditional knowledge · Resilience · Biological production system

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K. Takeuchi et al. (eds.), *Resilient Asia*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56597-0_3

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3.1 Raising Livestock to Enhance Resilience in Developing Countries

It is commonly understood that low-income households in developing countries encounter the risk of income variation and consumption variation caused by income variation because of imperfect markets, particularly in those lacking perfect financial markets.[1] The ability to smooth consumption under external shocks to income is very important for households in developing countries under those circumstances. Assets for agricultural production such as livestock, land, grain, and human capital are used, frequently, for consumption smoothing by households in developing countries without accessing to financial organizations when encountering external shocks.[2] Livestock is one of the major measures for consumption smoothing. Markets in many countries in Southeast Asia have matured to approach perfect markets with economic growth in recent years. Farmers in those countries have opportunities to generate income by selling their products, which contributes to income smoothing. It also provides measures for consumption smoothing. Vietnam, which is the main research target in this chapter, has also experienced rapid economic development like other countries in Southeast Asia since the late 1980s by implementing Doi Moi. They have traditional home garden systems similar to Indonesia and Sri Lanka, which is called the VAC system. The typical VAC system comprises trees for fruit (Voun), ponds for aquaculture (Ao), and livestock (Chuong). This system is effective for consumption smoothing as households rely heavily on self-consumption, which means opportunities to generate income and measures for income smoothing are limited. In addition, this VAC system is rather small; not only the inputs for the system but also the outputs along with the by-products from the system do not affect the environment. The traditional VAC system has been

[1]There are many previous studies concerning income and consumption smoothing under external shocks: for instance, Ligon and Schecter (2002, 2003), Ito and Kurosaki (2007), Jalan and Ravallion (2001), Kurosaki and Fafchamps (2002), and Kurosaki (1995).

[2]Liquidity among those assets is different. Sure, holding high liquidity assets is critical for the households to respond to external shocks. Liquidity of assets for agricultural production is not so high in some cases. Moreover, values of those assets tend to be decreased because of external shocks affecting the area overall, including extreme weather event. Under those circumstances, consumption smoothing by using those assets is not workable. Farmers encountering external shocks prefer to hold livestock rather than to sell the livestock in many sub-Saharan African countries (Fafchamps et al. 1998, Hoddinott 2006 and Kurosaki 2009).

considered a rather highly resilient system from the perspective of those features. The traditional VAC system is undergoing transformation because of rapid economic growth with globalization, which can be considered as external shock. Resilience of farmers is consumption smoothing to respond to those external shocks. Farmers are allowed to access the market to make profits so that they may obtain income, for which the highest liquidity assets are the most effective for consumption smoothing. Particularly, they have an incentive to introduce livestock because the developing market is not sufficient to provide perfect liquidity for income and consumption smoothing, and they are able to cope with frequent, extreme weather events. Livestock have a high affinity to VAC; however, livestock raised in recent years is rather commercialized. Knowledge of feeding technology for the livestock and access to markets are needed to make profits in order to introduce the livestock. Therefore, a leading farmer must take risks to feed the livestock and have access to inputs with credit to purchase it. Farmers are able to obtain those through social networks in the community, which is also an important asset in developing countries.

The purpose of this chapter is to reveal factors to introduce or raise livestock by farmers to respond to external shocks such as rapid economic growth with globalization and extreme weather events. Risk behaviors of farmers, social networks, and credit constraints are considered the main factors in this chapter. The target research area is the northern part of Vietnam around the Red River Delta. An overview of the research area is provided in the next section followed by a section discussing the theory of risk behavior proposed by Binswanger. That is followed by a section where estimation is implemented and the estimation results are presented. This chapter is summarized in the final section.

3.2 Overview of Research Area

Household surveys have been conducted in three communities, Giao Long, Giao Thien, and Giao Xuan, located in the Red River estuary in the northern part of Vietnam. One hundred forty-nine households in Giao Long, 150 households in Giao Thien, and 151 households in Giao Xuan have been covered from December 3–22, 2012, from January 22–29, 2013, and from January 14–21, 2013, respectively. Of course, basic information about the households in addition to detailed information about agricultural production, aquaculture, and related information have been mainly collected through the questionnaire surveys. In addition to that information, risk preferences, credit constraints, and social network information have also been collected. In particular, some types of data, including agricultural production, were queried for 2000–2012 very carefully to create a sort of panel data.

The population in 2010 in those three communities was 7672 (Giao Long), 9486 (Giao Thien), and 9232 (Giao Xuan).[3] It is recognized that there is a decreasing

[3]These data and the following data related to paddies and livestock were obtained from several institutions through field surveys.

population in those three communities when comparing those with the population figures for 2005, 8362 (Giao Long), 10,286 (Giao Thien), and 9486 (Giao Xuan). However, the number of households has increased or remained stable from 2005 to 2010: a total of 2503 in 2005 compared to a total of 2511 in 2010 in Giao Long, 2317–2646 in Giao Thien, and 2466–2732 in Giao Xuan. It is implied that the number of households has increased because of economic activities including agriculture developing in a dynamic way, but average household size has decreased. It is observed in the field that farmers cannot help facing changes in their lifestyle including agricultural production to respond to the surging market economy.

Figure 3.1 indicates the trend in average land productivity of paddies from 2000 to 2012 from field survey in 2012 and 2013. Productivity changes have been caused by idiosyncratic reasons and aggregate shocks, and the main reasons for aggregate shocks are extreme events such as drought, floods, and insect infestation. Remarkable decreasing land productivity in paddies can be found for 2005, 2009 and 2012 in the figure.[4] It may be noted that the frequency of those extreme events has increased as well as severity of those events. Rice production is the major farming activity in almost all Asian countries. Vietnam is one of the largest exporters of rice in Asia with Thailand because the government of Vietnam implements policies to enhance the productivity of rice. Rice production supports basic food intake of the

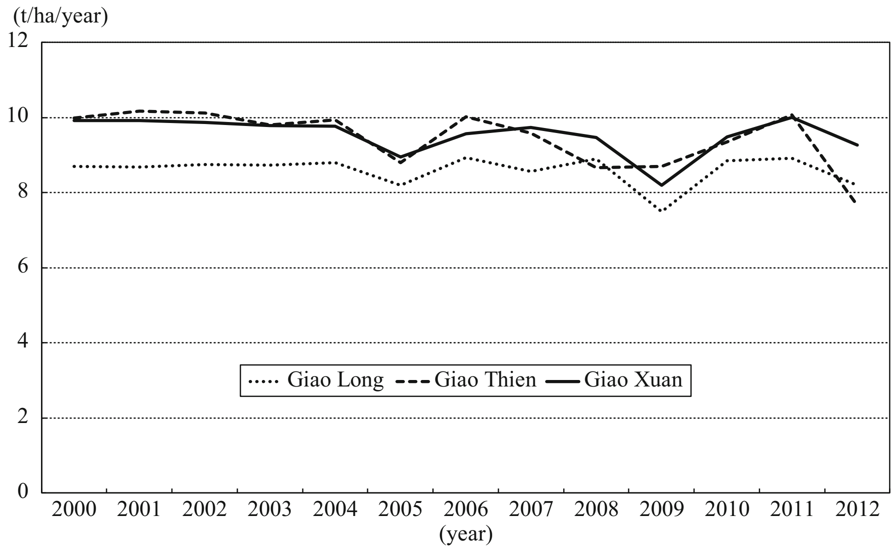

Fig. 3.1 The trend in average land productivity of paddies (2000–2012) (Source: Field Survey 2012 and 2013)

[4]The data in Fig. 3.1 are from a questionnaire survey. Findings mentioned are justified from interviews with experts such as government officials.

household. Almost all households engaged in farming have VAC system with paddy field. VAC system with rice production enhances resilience of the household.

Farmers in those three communities have introduced livestock under conditions of both the surging market economy and extreme events. Table 3.1 show raising livestock in research communities. While production in the paddies in the three communities has not varied widely, situations of raising livestock in those communities have done so. The number of cattle and buffalo increased remarkably in Giao Xuan although the trend in the number of cattle and buffalo in both Giao Thien and Giao Xuan remained almost the same. The numbers of pigs increased in all three communities. However, their numbers in both Giao Long and Giao Thien remained rather more stable than in Giao Xuan. The numbers decreased greatly in Giao Xuan. The amount of the production of poultry had increased in all three communities. The numbers of cattle and buffalo in Giao Long was much smaller than those in the two other communities. Poultry was raised in all three communities and was increasing in a stable manner. It is recognized that they for the most part raised larger animals, such as cattle and buffalo, which require certain specific skills, land, and feed. Information and credit are thus necessary. That means that a farmer who would like to raise larger animals has to be prepared to take risk. Farmers in Giao Xuan had increased the number of cattle and buffalo raised and had to decrease the number of pigs raised. Farmers in the two other communities preferred pigs to cattle and buffalo as seen from the rather stable number of pigs raised. The number of cattle raised in Giao Long was much less than in the two other communities. It is noted from Table 3.1 that farmers in those three communities decided on the types of livestock to introduce into their farming systems based on considering information about skills, the capacity of the land, and finances, including the possibility of obtaining formal/informal credit based on the production of paddies and poultry. Farmers in Giao Xuan tend to take more risk than farmers in the two other

Table 3.1 Raising livestock in targeted research communes

Commune/Year		2006	2007	2008	2009	2010
Giao Long	Cattle/Buffalo (Number)	120	70	100	69	61
	Pig (Number)	3680	3650	2875	3008	3417
	Production of poultry (t)	278	332	454	508	588
Giao Thien	Cattle/Buffalo (Number)	273	308	218	154	174
	Pig (Number)	4352	4520	4504	4120	3813
	Production of poultry (t)	278	356	417	419	444
Giao Xuan	Cattle/Buffalo (Number)	47	313	250	171	192
	Pig (Number)	4050	4120	2837	2890	2501
	Production of poultry (t)	304	401	495	497	526

Source: Field Survey 2012 and 2013

communities. The least risk takers among the three communities are found in Giao Long. The case of Giao Thien lies in between Giao Xuan and Giao Long.

3.3 Risk Behaviors of Farmers

3.3.1 Theoretical Framework of Risk Behaviors of Farmers

The framework proposed by Binswanger (Binswanger 1981, 1980, 1978a, b, and Miyata 2003) is applied for this study to capture risk attitudes of farmers in all three communities. Binswanger established an experimental method in the field to capture a partial relative risk aversion proposed by Menezes and Hanson (1970) and Zeckhauser and Keeler (1970).

W represents the expected final wealth and is defined as follows:

$$W = f\ddot{O} + M \tag{3.1}$$

$f\ddot{O}$ is initial wealth, and M is prospect of new wealth. This definition is from prospect theory proposed by Kahneman and Tversky (1979) to explain more realistic decisions under uncertainty. An individual utility function is represented by $U(W) = U\left(f\ddot{O} + M\right)$. Relative risk aversion (PRA) is calculated as follows, when Q represents absolute risk aversion (ARA: Pratt (1964)):

$$\text{PRA} = -W\frac{U'}{U''} = WQ \tag{3.2}$$

$U^{'}$ and $U^{''}$ are the first derivative and second derivative of the utility function, respectively. PRA in this framework is allowed to be changed so that the heterogeneity of individual persons or households may be captured although PRA is assumed not to decrease (Arrow (1971)) and remains constant, which is called constant relative risk aversion (CRRA). Kessler and Wolff (1991) and Zhang and Ogaki (2000) indicate a decreasing PRA. A partial risk aversion (PRRA) is represented from PRA as follows:

$$\text{PRRA}(\omega + M) = -M\frac{U'(\omega + M)}{U''(\omega + M)} \tag{3.3}$$

As is seen from (3), *PRRA* captures the risk attitude when the prospect of new wealth M is changed with constant initial wealth ω. From (2) and (3), the relationship among three types of risk aversions is shown below:

$$\mathrm{RRA} = \omega \mathrm{ARA} + \mathrm{PRRA} \tag{3.4}$$

This relationship indicates that RRA is able to increase as PRRA is increasing while assuming a constant ARA and increases in the prospect M although RRA is assumed to be generally constant.

3.3.2 Measuring Risk Behaviors of Farmers

We designed a game for hypothetical investment to estimate partial risk aversion in the research area.[5] Table 3.2 shows the game for hypothetical investment used in the field. Four types of the game are provided in total. Differences among those four games indicate initial investment and payoffs. For *Games* 1, 2, 3, and 4, 2000 VND, 10,000 VND, 20,000 VND, and 200,000 VND are indicated, respectively. Each game has five scenarios for both cases of failure and success, of which the probabilities are the same: 50% for failure and 50% for success. Farmers targeted in the survey are requested to choose one business type or payoff. In the case of *Game* 1, farmers are supposed to invest 2000 VND for one game while considering each type of payoff. If the farmer chooses business type 2, he/she is expected to earn 240,000 for success of the investment with 50% probability and 50% probability for failure of the investment at 80,000. Business types 1, 2, 3, and 4 are considered "extreme risk aversion," "severe risk aversion," "moderate risk aversion,"

Table 3.2 Game for hypothetical investment

Game 1. Initial investment cost is: 2000 VND Game 2. Initial investment cost is: 10,000 VND **Payoff for Investment Game 1 & 2**					
Business type	1	2	3	4	5
Fail (VND)	100,000	80,000	60,000	40,000	0
Succeed (VND)	100,000	240,000	300,000	320,000	600,000
Game 3. Initial investment cost is: 20,000 VND Game 4. Initial investment cost is: 200,000 VND **Payoff for Investment Game 3 & 4**					
Business type	1	2	3	4	5
Fail (VND)	200,000	160,000	100,000	40,000	0
Succeed (VND)	200,000	340,000	600,000	660,000	1,000,000

[5] A constant risk aversion (CRA) utility function is assumed in this research as follows (Binswanger (1981), Binswanger (1980), Binswanger (1978a), Binswanger (1978b), and Miyata (2003)).

$$\mathrm{U} = (1 - S)M^{1-S}$$

"inefficient risk aversion," and "neutral to negative risk aversion," respectively, because of the expected utility from expected income and partial according to a series of study of Binswanger (Binswanger 1981, 1980, 1978a, b) and Miyata (2003). *Game* 4 is seen as "inefficient risk aversion" because the expected payoff of *Game* 4 is the same as that of *Game* 3 but the variance is larger.

Figure 3.2 shows the distribution of the number of farmers for each chosen payoff type and risk aversion type. The number of farmers who chooses moderate

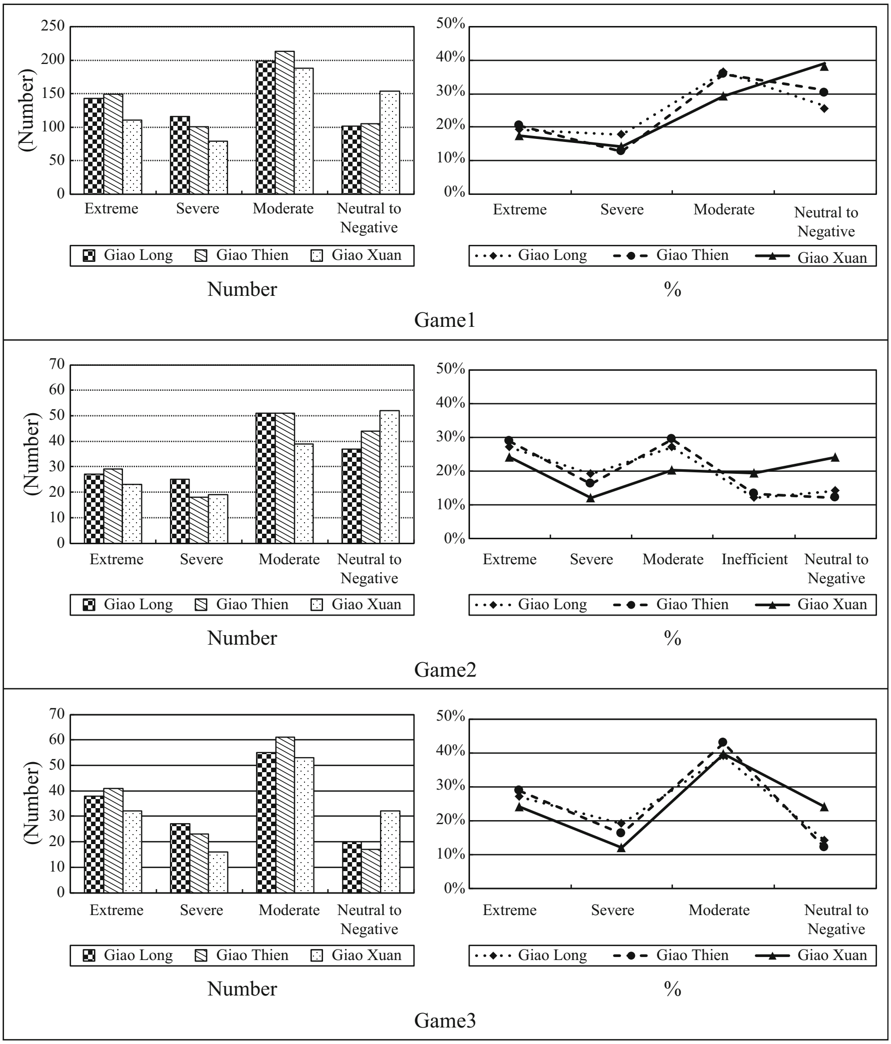

Fig. 3.2 Distribution of the number of farmers for each chosen payoff type (Source: Field Survey 2012 and 2013. Note: Extreme, severe, moderate and neutral to negative on the figure indicate "extreme risk aversion," "severe risk aversion," "moderate risk aversion," "inefficient risk aversion," and "neutral to negative risk aversion," respectively)

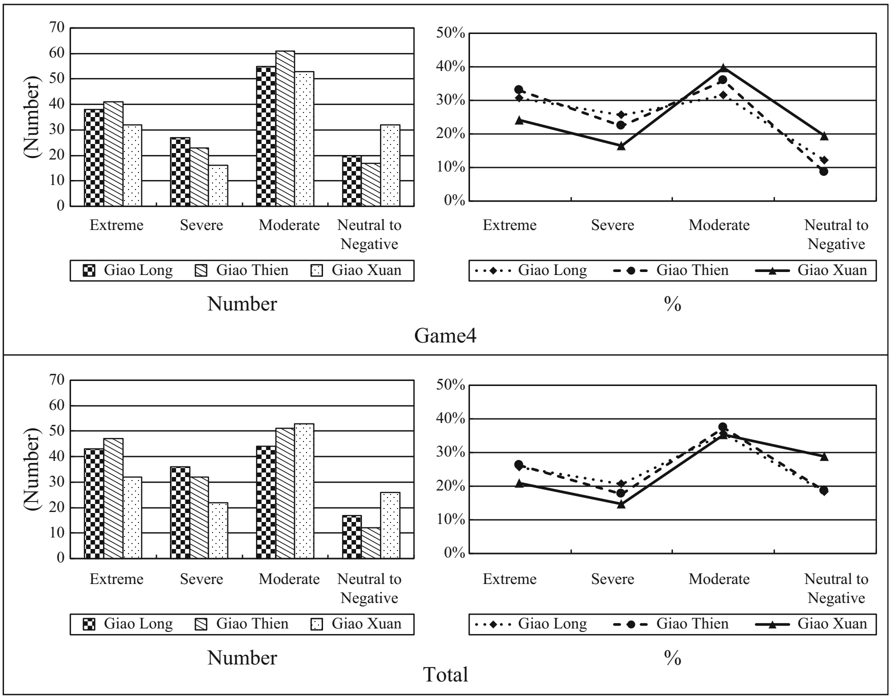

Fig. 3.2 (continued)

risk aversion including inefficient risk aversion or the ratio of them is found in almost all cases. In addition, the number of farmers who chose it and the ratio of them in Giao Xuan are larger than in the two other communities when neutral to negative risk aversion cases are focused on in each game. The tendency is found that farmers prefer to take risk in Giao Xuan as the number of farmers who choose extreme and severe risk aversions and the ratio of them there are smaller than in the two other communities. Taking risks by farmers in Giao Long is rather larger than that in Giao Thien, if it must be, although it is difficult to note the differences in risk preferences for the two other communities. The number of farmers who take more risk and the ratio of them decrease as the game proceeds. It is seen that they become afraid of losing rather large amounts of money with larger initial investment although the games are only hypothetical.

3.3.3 Factors of Risk Behaviors of Farmers

The ordered probit model is employed to identify factors to define types of risk aversions in each game. The estimation equation is shown below. y_i is an ordinal variable, which is the chosen business type by the farmer in this study:

$$y_i^* = x_i\beta + e_i$$
$$e_i \tilde{} N(0,1), \forall i = 1, \ldots, N$$
$$y_i = j, \mu_{j-1} < y_i^* \leq \mu_j$$

The results of the estimation are indicated in Table 3.3 with an explanation of the variables included in the estimations. *Age* is the age of respondent, and its expected sign can be either positive or negative. *Sex* is a dummy variable, which is assigned a value of 1 for male. *Native* is a dummy variable, which is assigned a value of 1 for the respondent having been born in the commune. The sign of the coefficient of

Table 3.3 Estimation results of factors of farmers' risk behaviors

Variable ID		Game 1	Game 2	Game 3	Game 4
Age	*Age of respondent*	−0.004	−0.004	0.000	0.005
		(0.530)	(0.500)	(0.050)	(0.640)
Sex	*1 if respondent is female*	−0.144	−0.188	−0.220	−0.280
		(0.700)	(0.920)	(1.080)	(1.360)
Edu	*Year of education*	0.014	0.007	0.064*	0.070**
		(0.390)	(0.180)	(1.720)	(1.880)
Native	*1 if respondent is born in the village*	−0.140	−0.426*	−0.290	−0.276
		(0.580)	(1.760)	(1.200)	(1.130)
Paddy_area	*Area of paddy field*	0.000	0.000**	0.000**	0.000***
		(1.580)	(2.250)	(2.140)	(2.740)
Network	*Number of acquaintances to ask about farming (maximum number is five)*	−0.081	−0.080	−0.160**	−0.170**
		(1.120)	(1.060)	(2.140)	(2.340)
Variety_animal	*Variety of animals in the household*	0.265**	0.102	−0.050	−0.089
		(2.310)	(0.900)	(0.450)	(−0.780)
d_gx	*Dummy variable of Giao Xuan*	0.559*	0.607**	0.572*	0.813***
		(1.800)	(1.960)	(1.830)	(2.600)
d_gt	*Dummy variable of Giao Thien*	0.209	0.174	0.028	0.082
		(0.700)	(0.590)	(0.090)	(0.270)
Obs		160	160	160	160
Log likelihood		12.75	13.17	15.92**	21.11**
Psudo R2		0.03	0.03	0.04	0.051

Note:
1. Absolute value of z-statistics in parentheses
2. *significant at 10% level; **significant at 5% level; ***significant at 1% level

native can be either positive or negative. It is possible to take risk or avoid risk because they have much knowledge of the area. *Paddy_area* is the area of paddy field. Its expected sign is positive because it is an asset of the household, so it may allow the people in the household to take risk. *Network* is the number of acquaintances to ask about farming, which is at most five. This variable is a sort of indicator of social capital. In addition, varieties of information sources reflected by this variable may support farmers to introduce new agricultural technology including new varieties, plants, and livestock. Therefore, the sign of *network* is expected to be positive. *Variety_animal* is the number of varieties of the animals raised by the household. The meaning of this variable is the same as *paddy_area*. Moreover, livestock is considered a measure of consumption smoothing (Jalan and Ravallion 2001 and Kurosaki 1995). The expected sign of *variety_animal* is positive. Variables *d_gx* and *d_gt* are dummy variables for Giao Xuan and Giao Thien, respectively.

Looking at the results in Table 3.3, it is found that *edu*, *native*, *paddy_area*, *network*, *variety_animal*, and *d_gx* are significantly different from 0 in the result of at least one game. The results of *edu* are consistent with hypothesis although only two results, *Game* 3 and *Game* 4, are positive and significantly different from 0. A result of *native* for *Game* 2, only, is negative and significantly different from 0. All the results of *paddy_area* except for *Game* 1 are positive and significantly different from 0, which are consistent with expected result. The results of *network* are negative and significantly different from 0 for *Game* 3 and *Game* 4. The expected sign of *network* is positive as farmers are assumed to obtain information of new agricultural technology, method of cultivating and fostering livestock, status of market, and other areas related to agriculture easily. However, the signs of *network* are negative. It is observed from the field survey, including interviews, that farmers who may be considered leasing farmers are rather independent and do not rely on other farmers. Conversely, followers rely on such networks. It appears that the signs of the results of *network* are negative from this sort of circumstance. *Variety_animal* is expected to be positive and significantly different from 0 as is *paddy_area*, but the estimation results show the results being as expected only in the case of *Game* 1. Dummy variables *d_gx* and *d_gt*, in order to ascertain character difference of two communities, Giao Thien and Giao Xuan, from Giao Long show that only *d_gx* is positive and significantly different from 0. The numbers of cattle and buffalo raised have increased in Giao Xuan as indicated in Table 3.1. It may be considered that farmers in the commune take more risk than those in the other communities.

3.4 Factors of Introducing Livestock

Factors of deciding livestock to raise are estimated in this section. Estimation for panel data is intended to be employed. Several variables are added to the variables used for ordered probit model to estimate the factors' relationship with risk chosen by farmers in section 9.3. *Yield_Paddy* and *Credit* are added. *Yield_Paddy* means the yield of the paddy during the year, and *Credit* means experience of constraints for access to credit, such as borrowing money from formal and informal money lenders. The definition of credit constraints or capturing experience of constraints for access to credit is implemented by applying the direct-elicitation method (DEM: Feder et al. 1990: Petrick 2004 and Scott 2000). The expected signs for the coefficients of the variables are the same as in the estimation for factors for risk behaviors of farmers by using ordered probit model in section 9.3. The expected signs of the added variables, *Yield_Paddy* and *Credit*, are positive and negative, respectively, because *Yield_Paddy* increases the profit from farming, which makes farmers invest in livestock, and *Credit* indicates that farmers do not have enough resources to invest in livestock. Farmers are asked whether they raised the livestock, which are cattle, buffalo, pig, poultry, duck, rabbit, and others for 12 years, from 2000 to 2012, to build panel data. Obtained information of raised animals are categorized into four, which are "cow," including cattle and buffalo; "pig"; "poultry," including chicken and ducks; and "others," including rabbits and others. Because the risk behaviors of farmer are captured through the game, we are unable to build panel data for the risk behaviors of farmer. Therefore, the estimated results of the ordered probit model to estimate factors of the risk behaviors of farmer, particularly *edu*, *paddy_area*, and *d_gx*, are used to estimate the risk behaviors of farmers for each year to complete the panel data. *Game i*, $i = 1, 2, 3, 4$, is the observed risk behavior from the questionnaire survey, and the estimated risk behavior uses the results of estimating the factors of the risk behaviors of farmers.

A panel logit model is employed to estimate the factors of introducing or raising livestock by farmers. Binary data for four categorized livestock, cow, pig, poultry, and others, is a dependent variable. Both fixed effect and random effect models are employed for the estimation:

$$y_{it}^* = X_{it}\beta + v_{it} + u_i$$
$$y_{it} = 1 \quad if \quad y_{it}^* > 0, and\ 0\ otherwise$$

Fixed effects model: $Cov(u_i, X_{it}) \neq 0$

$$\Pr[y_{it} = 1] = \Pr\left[y_{it}^* > 0\right] = \Pr\left[v_{it} > -X_{it}'\beta - \mu_i\right] = F\left(X_{it}'\beta + \mu_i\right)$$

Random effects model: $Cov(u_i, X_{it}) = 0$

$$\Pr[y_{it} = 1] = \Pr\left[y_{it}^* > 0\right] = \Pr\left[v_{it} + \mu_i > -X_{it}'\beta\right] = F\left(X_{it}'\delta\right)$$

Tables 3.4a, 3.4b, 3.4c, 3.4d, 3.4e, 3.4f, 3.4g, and 3.4h shows the results of the estimation. The id number of the result of the estimation on the top of the table includes the types of the game. The result of *Game i* on id number of the results of estimation (1) means observed risk behavior through questionnaire survey and estimated risk behavior by using the results of estimating the factors of risk behavior of farmers for *Game 1*.

Table 3.4a Estimation results of introducing livestock: cow, fixed effect

	(1)	(2)	(3)	(4)
Area_Paddy	-5E-05	-1E-05	-4E-05	-2E-05
	(0.400)	(0.850)	(0.380)	(0.150)
Yield_Paddy	−0.015	−0.020	0.001	0.007
	(0.340)	(0.450)	(0.020)	(0.160)
Age	−0.008	−0.011	−0.005	−0.005
	(0.790)	(1.140)	(0.470)	(0.550)
Sex	0.212	0.217	0.110	0.081
	(0.930)	(0.960)	(0.490)	(0.360)
Edu	−0.073*	−0.074*	−0.088**	−0.093**
	(1.650)	(1.700)	(1.990)	(1.980)
Credit	−0.330	−0.333	−0.270	−0.258
	(1.560)	(1.570)	(1.280)	(1.220)
Network	−0.025	−0.019	−0.018	−0.024
	(0.230)	(0.180)	(0.170)	(0.220)
Game i	1.905***	2.173***	0.467**	0.124
	(2.850)	(3.140)	(1.990)	(0.700)
d_gx	0.877*	0.815*	0.467**	1.093**
	(1.830)	(1.710)	(1.990)	(2.240)
d_gt	1.982***	1.980	0.467**	2.199***
	(4.290)	(4.310)	(1.990)	(4.680)
Obs	4715	4715	4715	4715
Log likelihood	−418.39	−414.43	−428.95	−430.94
LR chi^2	88.36***	96.28***	67.25***	63.25***
Hausman chi^2	−0.16	−0.28	−0.19	−0.17

Note:
1. Absolute value of z-statistics in parentheses
2. *significant at 10% level; **significant at 5% level; ***significant at 1% level

When results of the Hausman test, which is a test to compare the desirability of the fixed effects model versus the random effects model, are considered, only the case of the estimation result (4) of others is rejected, and all the other cases show the random effects model is desirable. The null hypothesis of the test is that the individual principle factor has no relationship with the dependent variable, tested by applying chi-squared test. The fixed effects model is rationalized if the null hypothesis is rejected.

The results for cows are almost the same whether with fixed effects or with random effects. *Edu* is negative and significantly different from 0. The expected sign of *edu* is positive. The estimation results for *Game i* are positive and significantly different from 0 in almost all cases except for *Game 4*. It means that bigger risk takers introduce cows. Farmers who raise larger livestock such as cows must consider taking risk because a larger amount of investment for the livestock is needed. It is difficult to obtain knowledge regarding raising livestock and the

Table 3.4b Estimation results of introducing livestock: cow, random effect

	(1)	(2)	(3)	(4)
Area_Paddy	-5E-05	-1E-04	-4E-05	-2E-05
	(0.400)	(0.850)	(0.370)	(0.150)
Yield_Paddy	−0.012	−0.018	0.003	0.008
	(0.290)	(0.410)	(0.070)	(0.200)
Age	−0.008	−0.011	−0.005	−0.005
	(0.830)	(1.150)	(0.520)	(0.570)
Sex	0.210	0.211	0.111	0.080
	(0.930)	(0.940)	(0.490)	(0.360)
Edu	−0.073*	−0.073*	−0.089**	−0.092**
	(1.660)	(1.690)	(2.010)	(1.990)
Credit	−0.330	−0.339	−0.267	−0.258
	(1.580)	(1.620)	(1.290)	(1.240)
Network	−0.025	−0.019	−0.019	−0.024
	(0.230)	(0.170)	(0.170)	(0.220)
Game i	1.907***	2.173***	0.467**	0.124
	(2.850)	(3.140)	(1.980)	(0.700)
d_gx	1.984***	1.983***	2.201**	2.211***
	(4.290)	(4.320)	(4.680)	(4.660)
d_gt	0.876*	0.814*	1.093**	1.110**
	(1.830)	(1.710)	(2.240)	(2.280)
Cons	−11.516***	−12.263***	−5.737***	−4.701***
	(4.190)	(4.370)	(5.500)	(5.370)
Obs	4715	4715	4715	4715
Log likelihood	−443.824	−439.874	−454.391	−456.3834
Wald chi2	50.920***	53.060***	53.710***	51.230***
Sigma_u	0.001	0.001	0.001	0.001
	(0.014)	(0.015)	(0.000)	0.014)
Rho	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)

Note:
1. Absolute value of z-statistics in parentheses
2. *significant at 10% level; **significant at 5% level; ***significant at 1% level

manner of selling the livestock, as the number of farmers who raise such larger animals remains limited. *d_gx* and *d_gt* are positive and significantly different from 0. Both communities are raising larger animals than Giao Long. It may be considered that both communities make larger profits and respond to a change in the market. Other variables are not significantly different from 0. *Edu* is also different from the expected results. Those results seeming to be affected by the number of farmers who raise larger animals remain limited.

Almost all estimated variables for pigs, by both fixed effects and random effects, have fallen line with the expected results. *Age* and *edu* are not significantly different

Table 3.4c Estimation results of introducing livestock: pig, fixed effect

	(1)	(2)	(3)	(4)
Area_Paddy	0.000***	0.000***	0.001***	0.000***
	(11.610)	(11.510)	(12.110)	(11.510)
Yield_Paddy	0.050	0.052	0.059***	0.059***
	(4.390)	(4.560)	(5.230)	(5.180)
Age	−0.003	−0.004	−0.004	−0.004
	(1.110)	(1.270)	(1.210)	(1.310)
Sex	0.471	0.463***	0.426***	0.430***
	(6.850)	(6.740)	(6.230)	(6.290)
Edu	−0.010	−0.012	−0.019	−0.025*
	(0.770)	(0.910)	(1.460)	(1.870)
Credit	−0.397***	−0.386***	−0.372***	−0.371***
	(6.110)	(5.960)	(5.770)	(5.750)
Network	0.051*	0.055**	0.056**	0.058**
	(1.860)	(1.980)	(2.040)	(2.120)
Game i	0.317***	0.226***	0.074***	0.094**
	(7.200)	(5.670)	(1.410)	(2.000)
d_gx	−1.075	−1.049***	−0.952***	−0.979***
	(13.450)	(9.860)	(9.110)	(9.210)
d_gt	−1.407***	−1.393***	−1.310***	−1.318***
	(10.100)	(13.320)	(12.740)	(12.780)
Obs	4715	4715	4715	4715
Log likelihood	−2823.397	−2834.379	−2850.13	−2849.104
LR chi^2	651.660***	629.690***	598.190***	600.240***
Hausman chi^2	2.170	0.270	−0.600	−3.670

Note:
1. Absolute value of z-statistics in parentheses
2. *significant at 10% level; **significant at 5% level; ***significant at 1% level

from 0, and the signs are not unexpected. Raising pigs may be considered a moderate farming strategy in terms of responding to the market to make a profit from observation in the field because it is not larger than cows, easier to feed than cows, and provides more profit than poultries. *Area_Paddy* and *Yield_Paddy* are positive and significant for both cases. *Area_Paddy* may be a security in ensuring access to credit. *Yield_Paddy* may also be a security in ensuring access to credit like *Area_Paddy*, but seems to play a role in securing working capital for farming, including raising livestock. Credit constraints have a negative impact on access to credit because *Credit* is negative and significantly different from 0. In addition, because *network* is positive and significantly different from 0, social networks support farmers to introduce or raise pigs. The estimation results of *network* for cows are insignificant. Farmers with entrepreneurship who raise cows do not rely on social networks, and they are considered to be taking risks at the forefront of the

Table 3.4d Estimation results of introducing livestock: pig, random effect

	(1)	(2)	(3)	(4)
Area_Paddy	0.000***	0.000***	0.000***	0.000***
	(11.570)	(11.460)	(12.060)	(11.460)
Yield_Paddy	0.046***	0.048	0.055***	0.055***
	(4.150)	(4.320)	(4.980)	(4.930)
Age	−0.002	−0.002	−0.002	−0.002
	(0.650)	(0.790)	(0.730)	(0.830)
Sex	0.464***	0.455***	0.419***	0.422***
	(6.770)	(6.650)	(6.140)	(6.200)
Edu	−0.008	−0.010	−0.017	−0.023*
	(0.610)	(0.740)	(1.290)	(1.720)
Credit	−0.411***	−0.401***	−0.386***	−0.385***
	(6.370)	(6.240)	(6.040)	(6.020)
Network	0.052*	0.055**	0.056**	0.058**
	(1.870)	(1.990)	(2.050)	(2.120)
Game i	0.321***	0.228***	0.077	0.095**
	(7.270)	(5.730)	(1.470)	(2.020)
d_gx	−1.068***	−1.042***	−0.943***	−0.970**
	(10.040)	(9.800)	(9.040)	(9.140)
d_gt	−1.409***	−1.394***	−1.310***	−1.318***
	(13.450)	(13.320)	(12.730)	(12.770)
Cons	−2.477***	−2.133***	−1.632***	−1.593***
	(4.190)	(8.490)	(6.330)	(6.860)
Obs	4715	4715	4715	4715
Log likelihood	−2866.543	−2877.735	−2877.735	−2892.761
Wald chi2	546.500***	530.520***	530.520***	503.880***
Sigma_u	0.000	0.000	0.000	0.000
	(0.007)	(0.007)	(0.007)	(0.008)
Rho	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)

Note:
1. Absolute value of z-statistics in parentheses
2. *significant at 10% level; **significant at 5% level; ***significant at 1% level

commune when considering the estimation results for pigs with those for cows. It is becoming popular to raise pigs to make larger profits in response to market conditions. Knowledge of raising pigs, including the way for trading them, has been accumulated in the commune. Then, even followers are able to raise them rather easily. Almost all estimation results for risk preference, *Game i*, with the exception of the case of *Game* 3 in random estimation results, are positive and significantly different from 0. Farmers taking more risk introduce and raise pigs. According to the estimation results, *d_gx* and *d_gt*, Giao Xuan and Giao Thien are

Table 3.4e Estimation results of introducing livestock: poultry, fixed effect

	(1)	(2)	(3)	(4)
Area_Paddy	0.000	0.000***	0.000***	0.000***
	(9.720)	(9.790)	(10.220)	(9.780)
Yield_Paddy	0.015	0.018	0.023**	0.020
	(1.250)	(1.450)	(1.840)	(1.610)
Age	0.000	0.000	0.000	0.000
	(0.140)	(0.090)	(0.100)	(0.110)
Sex	0.213***	0.198***	0.162***	0.186***
	(2.970)	(2.750)	(2.260)	(2.590)
Edu	−0.047***	−0.048	−0.048	−0.049*
	(3.400)	(3.550)	(3.550)	(3.510)
Credit	−0.239***	−0.227***	−0.213***	−0.221***
	(3.500)	(3.330)	(3.130)	(3.250)
Network	0.180***	0.179**	0.172**	0.177**
	(5.950)	(5.920)	(5.690)	(0.040)
Game i	0.118***	0.045	−0.128**	−0.002
	(2.750)	(1.110)	(2.230)	(0.040)
d_gx	−1.383***	−1.344***	−1.284***	−1.314***
	(11.120)	(10.820)	(10.560	(9.850)
d_gt	−1.218***	−1.187***	−1.136***	−1.159***
	(10.200)	(9.920)	(9.700)	(10.590)
Obs	4715	4715	4715	4715
Log likelihood	−2672.969	−2676.079	−2674.16	−2676.690
LR chi^2	388.780***	382.560***	386.400	381.340***
Hausman chi^2	−1.200	−3.410	4.210	−3.820

Note:
1. Absolute value of z-statistics in parentheses
2. *significant at 10% level; **significant at 5% level; ***significant at 1% level

introducing or raising pigs than is Giao Long. The number of cows in both Giao Xuan and Giao Thien has been increasing, while the number of pigs has been declining, as indicated in Table 3.1. Farmers in both communities are inferred to prefer raising cows to make larger profits, preferring higher risk. It may be considered that there are a rather large number of leading farmers who have responded to the market actively in those communities.

The estimation results for poultries for both the fixed effect and the random effect are almost the same as the estimation results for cows and pigs, but there are some points that are different from those of cows and pigs. *Yield_Paddy* is positive and significantly different from 0 in the cases of *Game* 3 for both the fixed effects and the random effects estimation. It is interpreted that *Yield_Paddy* may play a role in securing working capital for pigs. Considering the case of poultries, it may require less working capital to raise them. This may be reflected in the estimation

Table 3.4f Estimation results of introducing livestock: poultry, random effect

	(1)	(2)	(3)	(4)
Area_Paddy	0.000***	0.000***	0.000***	0.000***
	(9.720)	(9.780)	(10.210)	(9.770)
Yield_Paddy	0.015	0.018	0.022*	0.020
	(1.270)	(1.470)	(1.850)	(1.620)
Age	0.001	0.001	0.001	0.001
	(0.440)	(0.410)	(0.440)	(0.440)
Sex	0.207***	0.191***	0.155**	0.179**
	(2.890)	(2.670)	(2.170)	(2.500)
Edu	−0.045***	−0.047***	−0.047***	−0.048***
	(−3.330)	(−3.470)	(−3.460)	(−3.430)
Credit	−0.243***	−0.232***	−0.218***	−0.226***
	(−3.600)	(−3.440)	(−3.240)	(−3.360)
Network	0.180***	0.179***	0.172***	0.177***
	(5.950)	(5.910)	(5.690)	(5.830)
Game i	0.118***	0.044	−0.128**	−0.002
	(2.750)	(1.090)	(−2.230)	(−0.040)
d_gx	−1.381***	−1.342***	−1.282***	−1.312***
	(−11.110)	(−10.810)	(−10.540)	(−10.590)
d_gt	−1.219***	−1.187***	−1.137**	−1.160***
	(10.200)	(−9.920)	(−9.700)	(−9.850)
Cons	−0.199	0.049	0.530*	0.188
	(−0.750)	(0.190)	(1.930)	(0.770)
Obs	4715	4715	4715	4715
Log likelihood	−2716.757	−2719.885	−2717.952	−2720.479
Wald Chi2	320.000***	315.970***	321.440***	315.860***
sigma_u	0.001	0.001	0.001	0.001
	(0.010)	(0.010)	(0.010)	(0.010)
rho	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)

Note:
1. Absolute value of z-statistics in parentheses
2. *significant at 10% level; **significant at 5% level; ***significant at 1% level

results for poultries. The estimation results for *edu* are negative and significantly different from 0 in the case of the random effect estimation. It is not only true of the estimation results for poultries but also of others that the estimation results of *edu* are difficult to interpret. Further altering of estimation is needed from this perspective. The same results for *Credit*, *network*, *d_gx*, and *d_gt* are found with those of cows and pigs. Interesting estimation results for poultry are regarding risk preference, *Game i*. Only estimation results for both *Games* 1 and 3 are significantly different from 0. However, a farmer who prefers less risk, an extreme risk averter indicated at *Game* 1, introduces and raises poultries because the estimation results for *Game* 1 are positive. In the case of moderate risk preference, indicated in *Game* 3, the sign of the estimation results is negative. Those farmers do not prefer poultries. A farmer who takes more risk introduces and raises cows and pigs rather than poultries.

Table 3.4g Estimation results of introducing livestock: other, fixed effect

	(1)	(2)	(3)	(4)
Area_Paddy	0.000***	0.000***	0.000***	0.000***
	(5.280)	(5.260)	(5.140)	(5.300)
Yield_Paddy	−0.064***	−0.064***	−0.062***	−0.065***
	(3.540)	(3.540)	(3.450)	(3.590)
Age	0.021***	0.021***	0.021***	0.020***
	(4.990)	(4.990)	(4.980)	(4.980)
Sex	0.109	0.108	0.083	0.119
	(1.180)	(1.170)	(0.900)	(1.290)
Edu	0.015	0.015	0.016	0.012
	(0.840)	(0.830)	(0.920)	(0.640)
Credit	0.360***	0.361***	0.381***	0.354***
	(4.050)	(4.060)	(4.290)	(4.020)
Network	0.198***	0.198***	0.191***	0.201***
	(4.060)	(4.060)	(3.910)	(4.110)
Game i	−0.003	−0.006	−0.142**	0.041
	(0.050)	(0.110)	(2.000)	(0.640)
d_gx	1.696***	1.698***	1.740***	1.672***
	(8.460)	(8.440)	(0.200)	(8.320)
d_gt	2.059***	2.061***	2.093***	2.047***
	(10.730)	(10.700)	(0.191)	(10.740)
Obs	4715	4715	4715	4715
Log likelihood	−1799.729	−1799.724	−1797.77	−1799.521
LR chi^2	497.900**	497.910***	501.810***	498.310***
Hausman chi^2	−4.860	−3.440	−6.310	37.820***

Note:
1. Absolute value of z-statistics in parentheses
2. *significant at 10% level; **significant at 5% level; ***significant at 1% level

Other animals such as rabbits are also raised in the research field. The estimation results for others are almost the same, whether being with fixed effects or with random effects. *Area_Paddy* is negative and significantly different from 0 in all cases, which are different from the results for pigs and poultries. *Yield_Paddy* is also negative and significantly different from 0. These results are the opposite of the results for pigs. The estimation results for *Age* and *Sex* are positive and significantly different from 0 and insignificantly different from 0, respectively, while the estimation results for *Age* and *Sex* for pigs and poultries are insignificantly different from 0 and significantly different from 0. The results for *Credit* for others, which are positive and significantly different from 0, are different from those of pigs and poultries. The estimation results for *network* are positive and significantly different from 0. The parameters of *Game i* are not significant except in the case of *Game* 3, which are negative. The parameters of dummy variables, *d_gx* and *d_gt* for Giao

Table 3.4h Estimation results of introducing livestock: other, random effect

	(1)	(2)	(3)	(4)
Area_Paddy	-3E-04***	-3E-04***	-3E-04***	-3E-04***
	(5.210)	(5.180)	(5.070)	(5.230)
Yield_Paddy	−0.057	−0.057***	−0.055***	−0.058***
	(3.190)	(3.190)	(3.100)	(3.240)
Age	0.019***	0.019***	0.019***	0.019***
	(4.700)	(4.700)	(4.690)	(4.690)
Sex	0.118	0.117	0.092	0.128
	(1.280)	(1.270)	(0.990)	(1.390)
Edu	0.011	0.011	0.013	0.008
	(0.650)	(0.650)	(0.740)	(0.470)
Credit	0.373***	0.374***	0.393	0.367***
	(4.210)	(4.220)	(4.450)	(4.180)
Network	0.198***	0.198***	0.191***	0.201***
	(4.060)	(4.050)	(3.910)	(4.110)
Game i	−0.006	−0.008	−0.145**	0.039
	(0.100)	(0.150)	(2.050)	(0.620)
d_gx	1.680***	1.682***	1.723***	1.655***
	(8.390)	(8.380)	(8.630)	(8.250)
d_gt	2.052***	2.054***	2.084**	2.039***
	(10.700)	(10.670)	(10.900)	(10.700)
Cons	−4.306***	−4.300***	−3.928***	−4.400***
	(10.590)	(10.860)	(9.710)	(11.680)
Obs	4715	4715	4715	4715
Log likelihood	−1849.292	−1849.286	−1847.240	−1849.1
Wald chi2	294.680***	294.650***	296.010***	295.400***
Sigma_u	0.181	0.181	0.179	0.182
	(0.064)	(0.064)	(0.063)	(0.064)
Rho	0.010	0.010	0.010	0.010
	(0.007)	(0.007)	(0.007)	(0.007)

Note:
1. Absolute value of z-statistics in parentheses
2. *significant at 10% level; **significant at 5% level; ***significant at 1% level

Xuan and Giao Thien are positive and significantly different from 0 in all cases. Categorized livestock as other animals are rather small animals. It seems they are easier to raise than are larger animals such as cows and pigs. It is inferred from the estimation results that farmers who have experience of facing credit constraints and relying on networks prefer to raise those rather small livestock. In addition, their behaviors are not related to risk behavior, although it is found to be significantly different from 0 and negative. Those farmers must be small scale or not well commercialized.

Farmers raising livestock are large scale or favor making a profit in the market although the estimation results for cows with both the fixed effect and the random effect are not very clear because of the small number of cases, possibly not supporting that interpretation. Those farmers take risks and are not constrained by credit. With consideration of the differences in the estimation results of the yield of pigs from that of poultries, farmers who raise pigs favor the market more as it is inferred that they generate profit from their paddies. The land for paddies can be considered collateral, so the estimation results including it for both pigs and poultries are positive and significantly different from 0. While the estimated parameters for the yield of paddies for pigs are positive and significantly different from 0, those of poultries are not significantly different from 0 for all the cases, but except for, in *Game* 3, the rather risk preferred case. A positive relationship between raising pigs and the yield of paddies is found. Farmers who are able to achieve higher productivity of paddies favor making a profit from the paddies in the market and raising pigs. It is inferred that farmers who introduce or raise larger livestock such as pigs respond to the market economy to earn profits with a rather high-risk preference. Farmers with lower-risk preferences also raise smaller livestock such as poultries, etc. Those livestock may play a role in making their livelihood stable and may be related to the traditional VAC system. The estimated results for network are positive and significantly different from 0 in almost all cases. Social networks are an important factor to support the raising of livestock that is introduced for both reasons of making a profit in the market and of hedging risk. Information about livestock, including the manner of raising them, is disseminated through the social networks in the commune.

3.5 Summary

The purpose of this chapter is to reveal factors to introduce or raise livestock to respond to external shocks such as rapid economic growth with globalization and extreme weather events. Introducing the market economy is considered to have been an external shock to society. The villagers have a traditional home garden system, the so-called VAC, comprising trees for fruit, ponds for aquaculture, and livestock with high resilience. Because of the intrusion of the market economy, the traditional system is collapsing, although livestock can be considered a method to make smooth consumption in response to shocks. It is revealed in this chapter that farmers who favor making a profit from their agricultural products with rather high-risk preferences raise larger livestock such as cows and pigs. It is more difficult to raise larger livestock from the perspective of technology. Therefore, farmers who are risk lovers tend to introduce large livestock. The significance of networks is found in the estimation results. The technology for raising livestock as well as other information to respond to the introduction of the market economy is disseminated through the social network the farmer belongs to. Followers who are rather risk averse are also able to obtain the information.

Farmers in the targeted communities are coping with the intrusion of the market economy as an external shock. However, it is probably causing other unexpected problems in the area because of the loss of the stability of the traditional VAC system. Raising livestock to generate a profit in the market has gained greater focus. Larger inputs for livestock may have caused environmental degradation and must be examined. Raising livestock is one of the major methods to enhance the resilience of households through smoothing consumption. Generating a profit from selling in the market can accomplish that. While raising livestock may enhance the resilience, both generally and specifically at the household level, it is causing other unexpected problems such as a new environmental degradation. A proper balance between inputs and outputs must be estimated at some level such as the commune (estimation results will be affected by the boundary of the estimation) if new technology and systems are introduced. Intrusion of the market economy in developing countries, including in the targeted area in this chapter, has become much faster. Farmers have an incentive to cope with it to generate profits. The situation causes us to encounter difficulties.

References

Arrow KH (1971) Essay in the theory of risk bearing. North Holland, Amsterdam

Binswanger HP (1978a) Risk attitudes of rural households in semi-arid tropical India. Econ Polit Wkly 13(25):49–62

Binswanger HP (1978b) Attitudes towards risk: implications for economic and psychological theories of an experiment in rural India. Yale Univ Econ Growth Center Discus Paper 286:1–58

Binswanger HP (1980) Attitudes toward risk: experimental measurement in rural India. Am J Agric Econ 62(3):395–407

Binswanger HP (1981) Towards risk: theoretical implications of an experiment in rural India. Econ J 91(364):867–890

Fafchamps M, Udrym C, Czukas C (1998) Drought and saving in West Africa: are livestock a buffer stock? J Dev Econ 55(2):273–305

Feder G, Lau LJ, Lin JY, Luo X (1990) The relationship between credit and productivity in Chinese agriculture: a microeconomic model of disequilibrium. Am J Agric Econ 72 (5):1151–1157

Hoddinott J (2006) Shocks and their consequences across and within households in rural Zimbabwe. J Dev Stud 42(2):301–321

Ito T, Kurosaki T (2007) Weather risk, wages in kind, and the off-farm labor supply of agricultural household in a developing country. Am J Agric Econ 91(3):697–710

Jalan J, Ravallion M (2001) Behavioral response to risk in rural China. J Econ Dev 66(1):82–99

Kahneman D, Tversky A (1979) Prospect theory: an analysis of decision under risk. Econometrica 47(2):263–291

Kessler D, Wolff EN (1991) A comparative analysis of household wealth pattern in France and the United States. Rev Income Wealth 37(3):249–266

Kurosaki T (1995) Risk and Insurance in a Household Economy: role of livestock in mixed farming in Pakistan. Dev Econ 33(4):464–485

Kurosaki T (2009) Economic analysis for poverty and vulnerability (in Japanese). Keiso Shobo, Tokyo

Kurosaki T, Fafchamps M (2002) Insurance market efficiency and crop choices in Pakistan. J Dev Econ 37(2):419–445

Ligon E, Schecter L (2002) Measuring vulnerability: the director's cut. WIDER DP 2002/86, Helsinki: UNU-WIDER

Ligon E, Schecter L (2003) Measuring vulnerability. Econ J C95–C102

Menezes CF, Hanson DL (1970) On the theory of risk aversion. Int Econ Rev 11(3):481–487

Miyata S (2003) Household's risk attitudes in Indonesian villages. Appl Econ 35(5):573–583

Petrick M (2004) Empirical measurement of credit rationing in agriculture: a methodological survey. Agric Econ 33(2):191–203

Pratt JW (1964) Risk aversion in the small and in the large. Econometrica 32(1/2):122–136

Scott K (2000) Credit. In: Grosh M, Glewwe P (eds) Designing household survey questionnaires for developing countries: lessons from ten years of LSMS experience, vol 2. The World Bank, Washington, DC

Zeckhauser R, Keeler E (1970) Another type of risk aversion. Econometrica 38(5):661–665

Zhang Q, Ogaki M (2000) Risk sharing in village India: the role of decreasing relative aversion. Ohio State University Department of Economics Working Paper 00-02: 1–25

Chapter 4
Enhancing Resilience to Climate Change and Disasters for Sustainable Development: Case Study of Vietnam Coastal Urban Areas

Mai Trong Nhuan, Nguyen Tai Tue, and Tran Dang Quy

Abstract Climate change is likely to intensify severe impacts of disasters and extreme weather events on resilience and sustainability of coastal urban areas. The solutions for enhancing sustainability and climate resilience of the coastal urban areas depend on multivariables and dimensions such as social, human, institutional, economic, and natural conditions and resources. It is therefore needed to develop a set of indicators for evaluating the adaptive capacity of urban systems and communities to climate change. In this chapter, we analyzed the status quo of climate variability, climate-related disasters, vulnerability, and adaptive capacity to climate change of Da Nang city, Vietnam, for developing a proposal of response measures to climate change. Results showed that Da Nang city has been impacted by several disasters, consisting of typhoons, floods, sea level rise, drought, saline intrusion, landslides, erosions, and forest fires. The vulnerability to climate change and disasters of Da Nang city is classified into low, average, high, and very high levels. The measures for reducing vulnerability and enhancing resilience to climate change and sustainability include increasing the resilience of natural environments and ecosystems and social systems, enhancing the urban governance for climate change adaptation, and promoting the transformative capacity from climate change to sustainable development opportunities.

Keywords Resilience · Adaptive capacity · Climate change · Disasters · Sustainable development · Da Nang city

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K. Takeuchi et al. (eds.), *Resilient Asia*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56597-0_4

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4.1 Introduction

Climate change is a current reality, being a critical threat (Leichenko 2011) and sustainable development (UN 2015) for the urban systems. Communities in the fast-growing cities and megacities of the developing countries are particularly vulnerable to extreme events and climate-related disasters due to the lower level of infrastructure development. Climate change-induced natural disasters can therefore impede sustainable development by destroying infrastructure and housing (Hallegatte et al. 2013), causing extensive economic damage (IPCC 2012), disease (Wu et al. 2016), and livelihood and human health problems (Hasegawa et al. 2016). Additionally, the very high rate of the spontaneous urbanization can lead to an increase in the utilization of fossil fuels, population, urban heat islands, land-use change, social inequality, and more conflicts over scarce resources. As a consequence, the urbanization has a potential to intensify the existing climate change challenges faced by the urban populations in the developing countries. The combination of climate change and the spontaneous urbanization will particularly pose the threat to lives and livelihoods of urban communities and sustainable development. IPCC (2012) has stated that 200 million people must be migrated from climate-related disasters by 2050, and the most vulnerable cities to climate change will be located in the developing countries. Building urban resilience to climate change is, therefore, one of the top priorities for sustainable development. Besides climate change mitigation measures that municipalities have implemented, cities today need to focus on the implementation of policies and actions to increase the adaptation to climate change. In the context of climate change, urban adaptation to climate change is defined as the ability of the urban system, entity, communities, and person to withstand impacts from climate change and disasters while still maintaining its essential functions (Leichenko 2011). The adaptation of urban areas to climate change includes the natural and social resilience and the ability to transform the climate challenges to opportunities for resisting and recovering from climatic disturbance. In which, natural resilience is defined as the ability of natural environments and ecosystems to resist and absorb climatic disturbance. The social resilience emphasizes the capacities of cities, infrastructure, communities, and persons to resist and quickly and effectively recover from the climatic disturbance (Folke 2006).

The coastal areas of Vietnam host approximately 45 million people (GSO 2015), who are highly exposed to climate change and climate-related disasters, including typhoons, floods, erosions, sea level rise, saline intrusion, and drought. These challenges concurrently with inappropriate planning practices, high dependency on natural resources (e.g., energy, water, forest, etc.), and lack of the disaster defenses will cause the coastal cities of Vietnam to become greatly vulnerable. In such context, enhancement of resilience of the urban systems is urgently needed to reduce the climate change impacts and to implement adaptation and mitigation efforts in the urban regions (MONRE 2012). This chapter first describes the varying levels of vulnerability to natural disasters in Da Nang city. It then proposes a framework for measuring adaptive capacity to climate change of Da Nang city. The chapter ends with a proposal of response measures for enhancing resilience to climate change in Da Nang city.

4.2 Overview of Da Nang City

Da Nang city is located on the central coast of Vietnam, connecting the Hanoi Capital in the north and Ho Chi Minh City in the south (Fig. 4.1). Da Nang is one of the most important economic-political cities of Vietnam, being a crucial city of the Central Key Economic Zone and an international trade corridor connecting Laos, Myanmar, and Thailand with other countries by its air- and seaport systems. Da Nang city covers an area of 1283.42 km^2, consists of six urban districts (Cam Le, Hai Chau, Thanh Khe, Lien Chieu, Ngu Hanh Son, and Son Tra), one suburban district (Hoa Vang), and Hoang Sa Island district. The urban areas are radiating to the rural areas at a rapid pace. The urban population markedly increased in the period of 1995–2013, reached to 88% of the total population in 2013, being significantly higher than the national average of 34%.

Da Nang city is located within a tropical monsoon climate zone with a rainy season from August to December and a dry season from January to July. The average temperature, rainfall, and humidity are 26 °C, 2500 mm, and 83%, respectively. According to the climate change projection scenarios, climate change is likely to increase the intensity of moderate to severe rain events in Da Nang city, leading to increase flood disasters in both magnitude and frequency (Reed 2013).

4.3 Vulnerability of Da Nang City to Climate Change

4.3.1 Climate Variability

The mean temperature of the decade 1991–2000 rose by more than 0.4 °C in comparison to the decade 1931–1940. In the period from 2008 to 2013, Da Nang city has experienced many heat wave events during June and July with the temperature exceeded 35 °C. This is due to global warming and the development of buildings, replacement of pervious vegetated surfaces with impervious build

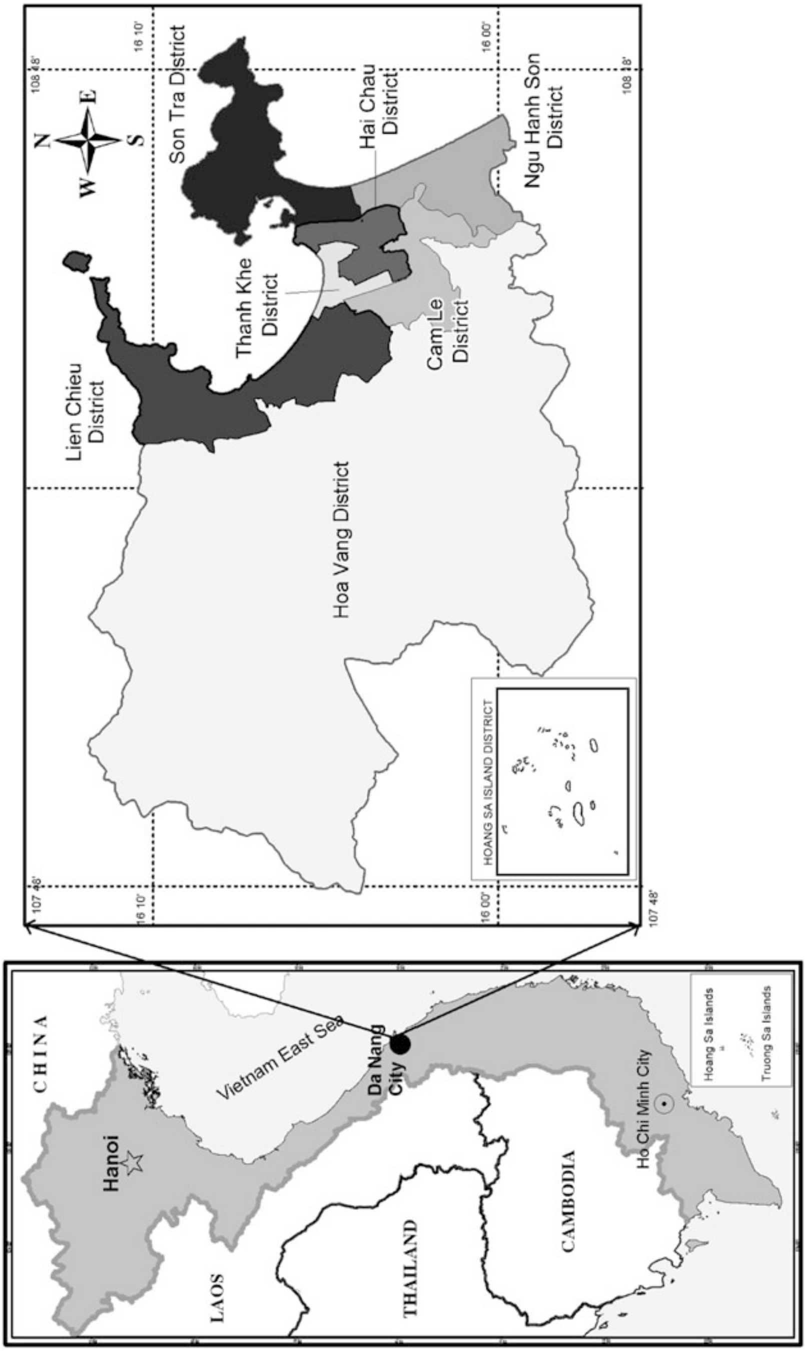

Fig. 4.1 The location of Da Nang city in Vietnam

Table 4.1 The danger levels of several disasters in the urban districts of Da Nang city

Districts	Typhoon	Flood	Landslide	Drought	Sea level rise
Son Tra	1	2	2	2	1
Lien Chieu	1	1	2	1	1
Thanh Khe	2	3	3	3	3
Ngu Hanh Son	2	1	2	1	1
Cam Le	3	1	3	2	–
Hai Chau	3	3	–	3	–
Hoa Vang	2	1	1	1	–

Source: ACCCRN (2009)
Note: 1, most serious; 2, average serious; 3, less serious; −, no data

surfaces, and other emissions of heat from transportation and industrial activities. The observed data of the period from 1976 to 1994 showed an increasing tendency of the average rainfall from 15 to 25 mm/year. Additionally, the number of years with total rainfall >2500 mm in the period of 1995–2008 was twofold higher than the period from 1976 to 1994.

4.3.2 Climate-Related Disasters

The climate-related disasters pose threats to resilience of the city in terms of the resident lives, livelihoods, and the socioeconomic development. The most dangerous disasters in Da Nang city have been examined to be typhoons, floods, drought, salinity intrusion, and landslides (ACCCRN 2009). Particularly, the climate-related disasters are projected to increase in frequency and intensity with climate change. Based on the loss of lives and properties, socioeconomic damage, and the resilient capacities of the natural and social systems, the danger levels of disasters are ranked for the urban districts of Da Nang city (Table 4.1).

4.3.2.1 Typhoons

Among disasters, typhoons are considered to pose the most threats to urban residents, livelihoods, and properties in Da Nang city. During the period from 1960 to 2013, a total of 35 typhoons and tropical depressions directly hit Da Nang city. The typhoon season is normally from August to November with higher frequency of the typhoons occurring between September and October. Recently, due to the effects of climate change, abnormal typhoons have taken place during June and July and caused severe damage for dwellers' lives, livelihoods, and properties. The most vulnerable areas to typhoons are Son Tra, Lien Chieu, and Ngu Hanh Son districts (Table 4.1). In the last decade, several violent typhoons attacked Da Nang city and caused significant injury, loss, and damage to human lives, livelihoods, homes, and infrastructure. Such impacts were seen in the typhoons of Chanchu and Xangsane in 2006, Ketsana in 2009, and Nari in 2013. For example, the typhoon Xangsane caused severe damage to the whole city, particularly in Son Tra and Lien Chieu districts. The total damage was estimated to be that 33 people were killed, 289 people injured, 14,138 houses collapsed, 112,691 house roof damaged, 2760 classrooms damaged, 18,466 ha forests damaged, and 200 boats sank and that the electricity, post office, schools, roads, and aquaculture are also damaged. Total economic loss was up to 5290 billion VND (equal to half of city GDP in 2006) (ACCCRN 2009). Other examples of the violent typhoon could be shown by Ketsana typhoon which caused 8 people killed, 92 people injured, 283 houses collapsed, 8192 house roofs lost, 7000 ha damaged forests, and 495 billion VND economic loss (Da Nang People's Committee 2012). The exceptionally strong tropical typhoon in Da Nang city is similar to other regions in Southeast Asia (IPCC 2012), reflecting that the abnormal typhoon in Da Nang city may be related to the increasing trend of temperature (Coumou and Rahmstorf 2012). These evidences suggest that the number of violent typhoons in the future may increase following tendency of climate change (IPCC 2012).

4.3.2.2 Floods

Da Nang city is located in the downstream of three river systems, consisting of Vu Gia Thu Bon, Tuy Loan, and Cu De rivers, and surrounded by the high mountains and steep slope in the westward. Annually, several floods occur in the city during rainy season from September to November. Especially, the increased occurrence of heavy rainstorms has put urban communities in Da Nang city at risk for devastation from floods. The most vulnerable areas to floods are Lien Chieu, Cam Le, and Hoa Vang districts (Fig. 4.2). The flood often leads to very large social and physical damage, including human lives, houses, infrastructures, and industrial and agricultural products. Total economic loss due to floods from 1998 to 2013 was 2640 billion VND. An exemplified flood event occurred in the year 1998 that caused 11,179 ha of the city to be inundated 0.93 m in water depth. The total damage was the following: 37 people killed, 61 people injured, 4579 houses collapsed, and economic loss of 611 billion VND. The increasing trend of heavy rainfall in recent years will substantially intensify the frequency of floods (Cruz et al. 2007).

4.3.2.3 Sea Level Rise

According to MONRE (2012), sea level has been rising at a rate of about 3 mm/year along the shoreline of Vietnam, with the fastest recorded rates averaged along the coastal zone of central areas, including Da Nang city. The observed rate was

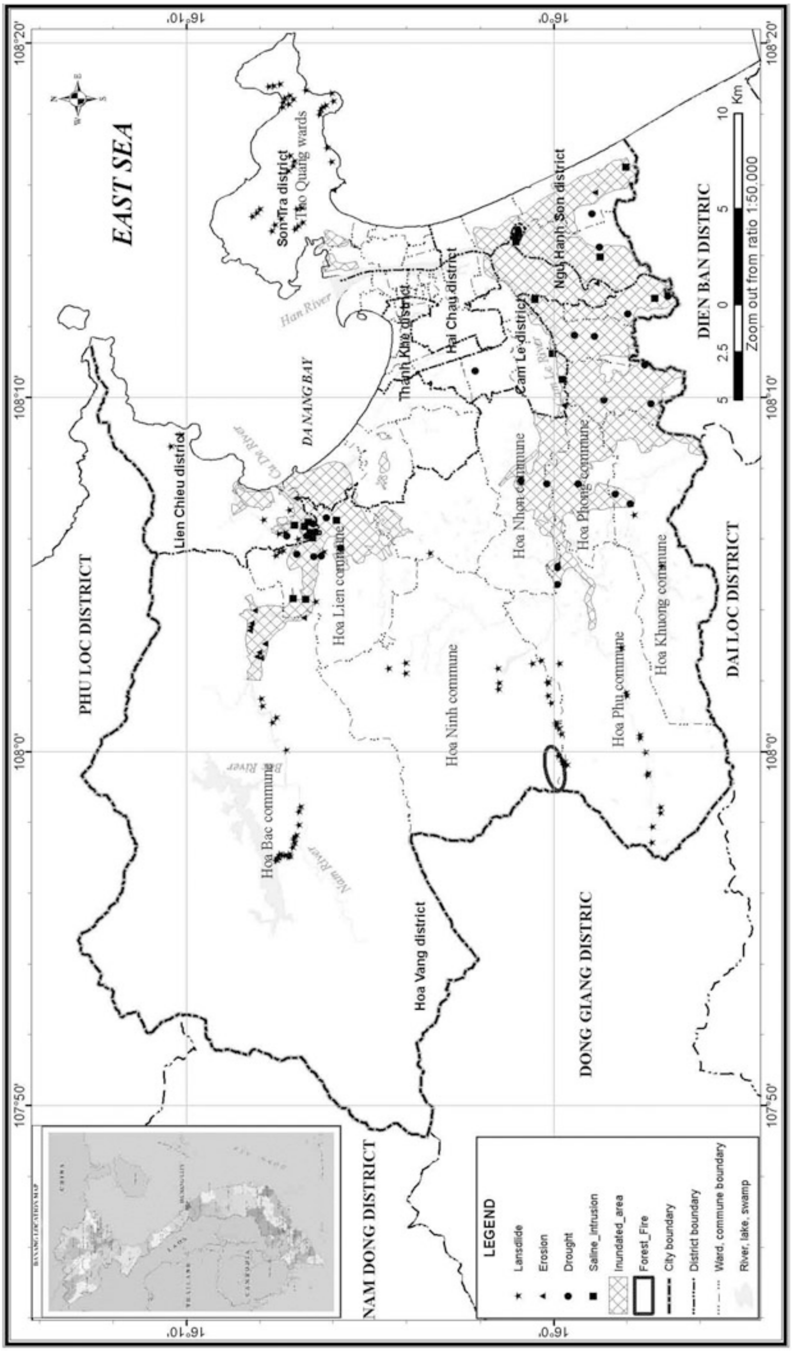

Fig. 4.2 Map showing disasters in Da Nang city

slightly lower than the global average of 3.1 mm/year (IPCC 2012). It has been estimated that by the year 2040, sea level rise in Da Nang may reach to 30 cm (MONRE 2012), submerging approximately 30,000 households. Additionally, sea level rise will intensify the flood disasters in the coastal areas. An estimate of the rate of sea level rise has reported that the global sea level would increase from 0.90 to 1.30 m by 2100 (IPCC 2012). If a sea level rise from 50 to 100 cm, the river water level in the urban areas would increase from 20 to 40 cm due to tidal influence. As a result, a large area of Da Nang city will be uninhabitable due to flooding and waterlogging. The sea level rise will increase the intensity of saline intrusion in the coastal and low elevation areas, causing degradation of agricultural lands and contamination of surface and groundwater.

4.3.2.4 Drought

Drought annually takes place following long hot periods from April to July. During the period from 1988 to 2002, there were four extreme drought years: in 1988, 1990, 1998, and 2002. The drought caused lack of water use for residents and agricultural activities in Lien Chieu, Ngu Hanh Son, Cam Le, and Hoa Vang districts. The drought in year 2002 caused the most severe impacts that caused a degradation of 500 ha rice fields, 200 ha aquaculture, and 10,000 ha forests.

The magnitude and frequency of drought tend to increase in Lien Chieu district (Hoa Hiep Bac and Hoa Hiep Nam wards), Cam Le district (Hoa Xuan, Can Tho, Dong Hoa, and Hoa Tho Tay wards), and Hoa Vang district (Hoa Bac and Hoa Phu communes). This pattern was explained by the reducing rainfall level and increasing temperature. In addition, urbanization is also considered to be an important factor inducing drought, particularly in Hoa Hiep Bac ward (Lien Chieu district) and Hoa Xuan ward (Cam Le district), because the increase in urban areas and population has led to reduce the forest areas and the groundwater recharge and to build more upland reservoirs, causing the reduce runoff and lower groundwater levels.

4.3.2.5 Saline Intrusion

Due to accelerating trends of drought and sea level rise, the seawater tends to faster intrude into the river estuaries and groundwater aquifers of Da Nang city. The observed data showed that the saline intrusion often occurs following the drought events, particularly during the extreme drought months. Currently, almost all river systems in Da Nang city are impacted by saline intrusion. If the saline intrusion is happening at a current rate, Da Nang city would lack water resources due to increase salinity in the surface water and ground aquifers. Saline intrusion has strongly influenced many socio-natural systems, including agriculture, water resources, and infrastructure. The saline intrusion extremely affects 700 ha of agricultural lands along the Vinh Dien and Yen river basins, causing degradation of livelihoods of 50,000 people in Hoa Quy, Hoa Hai, Hoa Xuan, Hoa Tien, Hoa Khuong, and Hoa Phong communes (Fig. 4.2). Local farmers do not have enough water resources for irrigating rice crops in these areas. Consequently, they have to switch to grow industrial crops (i.e., soybeans, green beans, corn, and flowers).

4.3.2.6 Landslides

There are 111 slope instabilities reported in Da Nang city, in which more than 20 instability blocks range from large (1000–100,000 m^3) to very large (>100,000 m^3). A very large block of landslide was observed in Tho Quang commune (Son Tra district) and Hoa Lien and Hoa Bac communes (Hoa Vang district) (Fig. 4.2). Almost all landslides occurred on the steep slope and thick weathering layers (30–40 m). The slope instability often triggers landslides during rainy season. The landslides threaten the safety of urban dwellers, infrastructure, and agriculture. Particularly, an unstable mountainside, stretching from the near shore to the top of Hai Van Pass (Lien Chieu district) with a size of 1.4 $\times$ 0.85 km, has been predicted to cause a giant landslide. If this happens, areas along the coastline of the Lien Chieu district and Da Nang Bay would be submerged under seawater due to extreme sea level rise.

4.3.2.7 Erosion

A total of 74 eroded riverbank locations have been observed throughout the river systems of Da Nang city (Fig. 4.2). The riverbank erosion strongly happened during the typhoon and flood events. The flood event that occurred in 1999 has eroded eight large riverbank locations with a total area of 7.97 km in length and from 0.5 to 1.5 m in width. The large eroded areas were observed in the riverbanks of Cu De and Tuy Loan Rivers (Fig. 4.2). Riverbank erosion caused the damage of houses, loss of lands and agriculture, and degradation of ecosystems.

Additionally, shoreline of Da Nang city is eroding with an alarm rate, causing loss of land and social resilience (i.e., infrastructure, housing, tourism landscape). The shoreline erosion seriously caused the damage of roads in Lien Chieu, Thanh Khe, and Son Tra districts. In which, the coastal areas in Lien Chieu districts have been eroded at the highest rate, containing a total length of 400 m and width of 100 m of the erosion area.

4.3.2.8 Forest Fire

An average of 10–15 forest fires has annually occurred, causing the deforestation from 2.5 to 17 ha in Da Nang city. During the period from 2005 to 2009, forest fire has caused the degradation of a total of 244.8 ha (Fig. 4.2). The recent forest fire occurred in June 21, 2014, and caused the deforestation of 100 ha *Acacia* forest (Da Nang People's Committee 2011). The forest fire frequency highly associates with long period of dry and hot weather. The magnitude and frequency of the forest fire are predicted to increase following the warming of climate.

4.3.3 Vulnerability of Da Nang City to Climate Change

Here we examine the vulnerability of Da Nang city based on the three elements, consisting of exposure level to disasters, sensitivity to disasters, and adaptive capacity of the socio-natural systems (IPCC 2007). Vulnerability of Da Nang city is examined to be four different levels (low, average, high, and very high levels). The correlation between vulnerability and hazard occurrence shows that the areas more exposed to the typhoon and flood disasters have the higher vulnerability, for example, Hoa Xuan commune (Cam Le district), Hoa Son and Hoa Phuoc (Hoa Vang district), and Hoa Quy and Hoa Hai communes (Ngu Hanh Son district) (Fig. 4.3). The low vulnerability areas relate to the high urban development (e.g., adequate physical infrastructure) and/or the maintenance of natural ecosystems and environments. As shown in Fig. 4.3, Son Tra and Thanh Khe districts have a low vulnerable level to disasters due to the lower exposure to disasters and the higher socio-natural resilience (i.e., adequate infrastructure and housing). The vulnerability of Lien Chieu and Cam Le districts is ranked as medium vulnerable level to disasters, reflecting that the high urbanization in these districts can increase the density of social element at risks, inadequate infrastructure protection, and degrading natural ecosystems and environments. Ngu Hanh Son and Hoa Vang districts are the most vulnerable districts to disasters due to the higher exposure to disasters and low economic development levels. The economic sectors (i.e., agriculture and aquaculture) that highly depend on the climate conditions still occupy a large proportion in these districts. The results demonstrated that the vulnerability of the urban areas is highly associated with the exposure levels to disasters and the socio-natural resilience.

4.4 Enhancement of Urban Resilience to Climate Change and Disasters for Sustainable Development

4.4.1 Adaptive Capacity Indicators to Climate Change

Quantification of the urban adaptive capacity will provide effective measures for local planning and monitoring changes and management practices to future climate

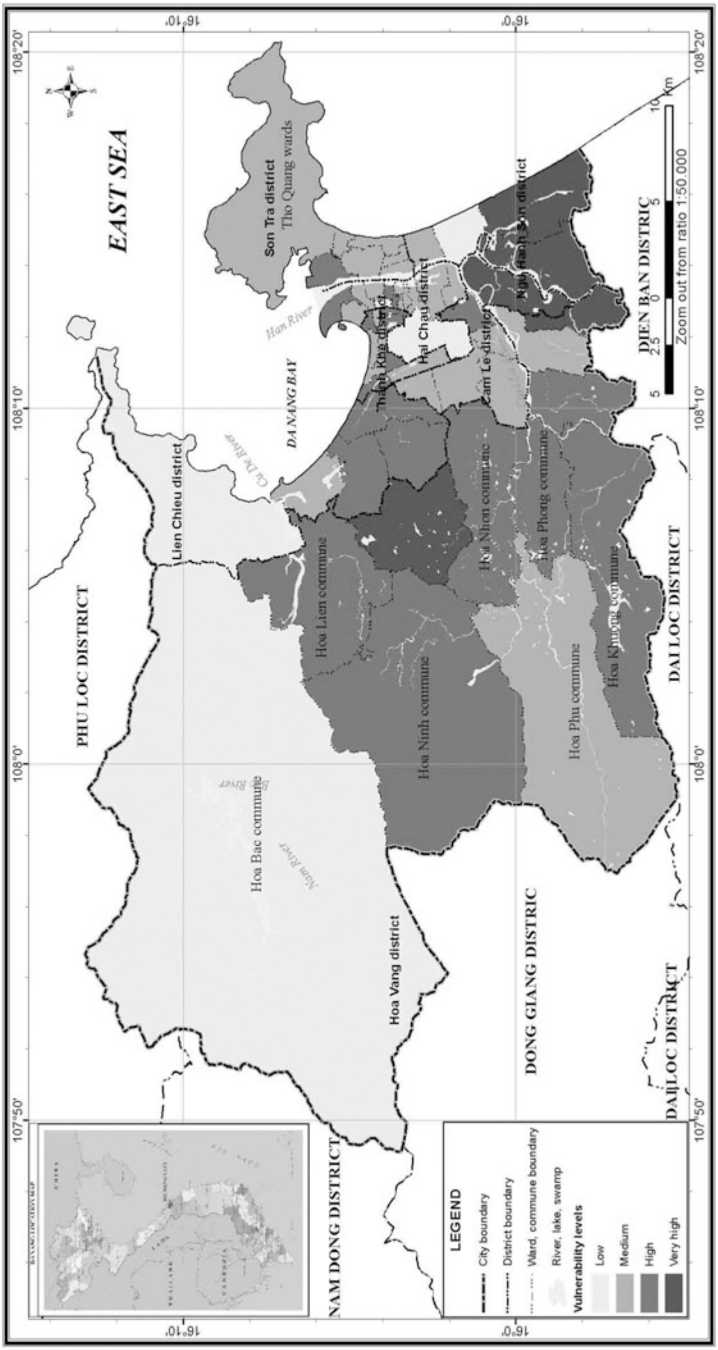

Fig. 4.3 Vulnerability map to climate-related disasters of Da Nang city

stimuli. Although the adaptive activities are somehow easy to recognize, the outcomes are not easy to determine (Nhuan et al. 2016). Over the last two decades, several conceptual frameworks have been proposed on developing adaptive capacity indicators to climate change for the urban areas (Leichenko 2011; Cutter 2013). Several approaches have been used to measure the adaptive strategies of local communities that relate to mobilization of the social capital and social networks and assets, for example, Adger et al. (2005). However, few studies have developed the indicator framework for evaluating the adaptive capacity of urban systems to climate change.

As shown in the previous section, Da Nang city has been threatened by climate variabilities and climate-related disasters that subsequently increase the vulnerability of the urban systems (ACCCRN 2009). The urban government and residents of the city are aware of the changing climate, especially with respect to the extreme weather events (i.e., heat waves, rainstorms) and climate-related disasters (i.e., typhoons and floods) (Reed 2013). Additionally, the local government has recognized that it is needed to increase the resilience to climate change by improving the socio-natural systems (Tuan et al. 2015). However, they have not had any approach to measure the adaptation of the urban systems and to integrate climate change adaptation into the urban planning, land-use planning, and other policies and plans. Therefore, we have developed an indicator framework for quantifying the adaptive capacity to climate change of Da Nang city. The adaptive indices are constructed based on the socio-natural resilience and the ability to transform the climate challenges to opportunities for sustainable development. This approach is highly relevant to measure the local climate resilience and useful in comparing across numbers of sectors and areas and to measure the outcomes of resilient planning of the urban systems. The natural resilience can be measured by numbers of indicators, including the ecosystem types, ecosystem services, biodiversity, water environment, soil environment, and topography (Olsson 2003). The social resilience can be measured by the indicators of the infrastructure and built environments, economic and financial systems, social and human systems, and urban governance (Adger 2000; Adger et al. 2005). The transformative capacities can be measured by several indicators such as planning, smart governance, innovation by communities, and development and assessment of smart technology (Table 4.2). According to Nhuan et al. (2016), the scoring method can be used to measure the adaptive capacity of each commune in Da Nang city. In this chapter, the interview method was used to collect adaptive capacity data of 25 households in 56 communes in Da Nang city. The data were then normalized to 0–1 scale to make results comparable. The initial values of quantitative data were transformed into 0–1 scale according to Eq. 4.1, while each initial qualitative data were converted to normalized scale based on expert evaluation.

$$x_{ij} = \frac{X_{ij} - MinX_{ij}}{MaxX_{ij} - MinX_{ij}} \tag{4.1}$$

Table 4.2 Adaptive capacity indicator framework to climate change

Components	Indicators
Natural resilience	
Geomorphological, geological, relief conditions	Diversification of geomorphology, geology, relief
Diversification of natural environment	Seminatural environmental areas
	Diversification of vegetation cover
	Species diversity
	Reclamation of coastal and riverine environment
Ecological and environmental conditions	Forest
	Urban green space
	Ecosystem service capital
Natural resources	Surface water resources
	Groundwater resources
	Tourism resources
Social resilience	
Infrastructure	Infrastructure for response to disasters
	Information systems
	Power systems
	Medical and health systems
	Education systems
	Transportation systems
	Water supply systems
	Waste treatment systems
Economic and financial systems	Revenue
	Livelihood
	Economic sectors
	Household economy
Society	Population
	Housing
	Education
	Medical services
	Labor
	Social inequality
	Social network
	Urban-rural linkage
Human	Education level
	Climate change perception
	Action ability

(continued)

Table 4.2 (continued)

Components	Indicators
	Health
Governance	Institutions, policy, strategy to adapt with climate change
	Administrative revolution
	Planning for climate change adaptation
	Infrastructure development
	Resource development
	Environmental, biodiversity management, and health protection
	Development of new rural areas, spontaneous urbanization management, and urban security
	Build, develop science and technology to adapt with climate change
	Controlling, monitoring, and accountability
	Integrated and interdisciplinary database
	National and international collaboration to fight with climate change
Transformative capacities	
Planning	Development orientation of sectors that adapt to climate change
Governance	Governance of climate change adaptation
Innovative communities	Innovation of disaster response
	Innovation in agriculture sectors for climate change adaptation
Development and assessment of smart technology	Climate adept models

For Eq. 4.1, x_{ij} is the standardized value of indicator i of the household j; X_{ij} is the value of the indicator i corresponding to household j; Max and Min denote the maximum and minimum scaled values of indicator i.

4.4.2 Assessment of Adaptive Capacity to Climate Change for Da Nang City

Using the adaptive capacity indicators in Table 4.2, the adaptive capacity of each commune to climate change in Da Nang city was assessed based on the averaged adaptive capacity scores of 25 households in each commune. The adaptive capacity to climate change could be divided into four levels, consisting of very high, high, medium, and low (Fig. 4.4). Results showed that the adaptive capacity to climate change of an urban district was related to social resilience, which includes the higher development of economy, infrastructure, and governance. The adaptive

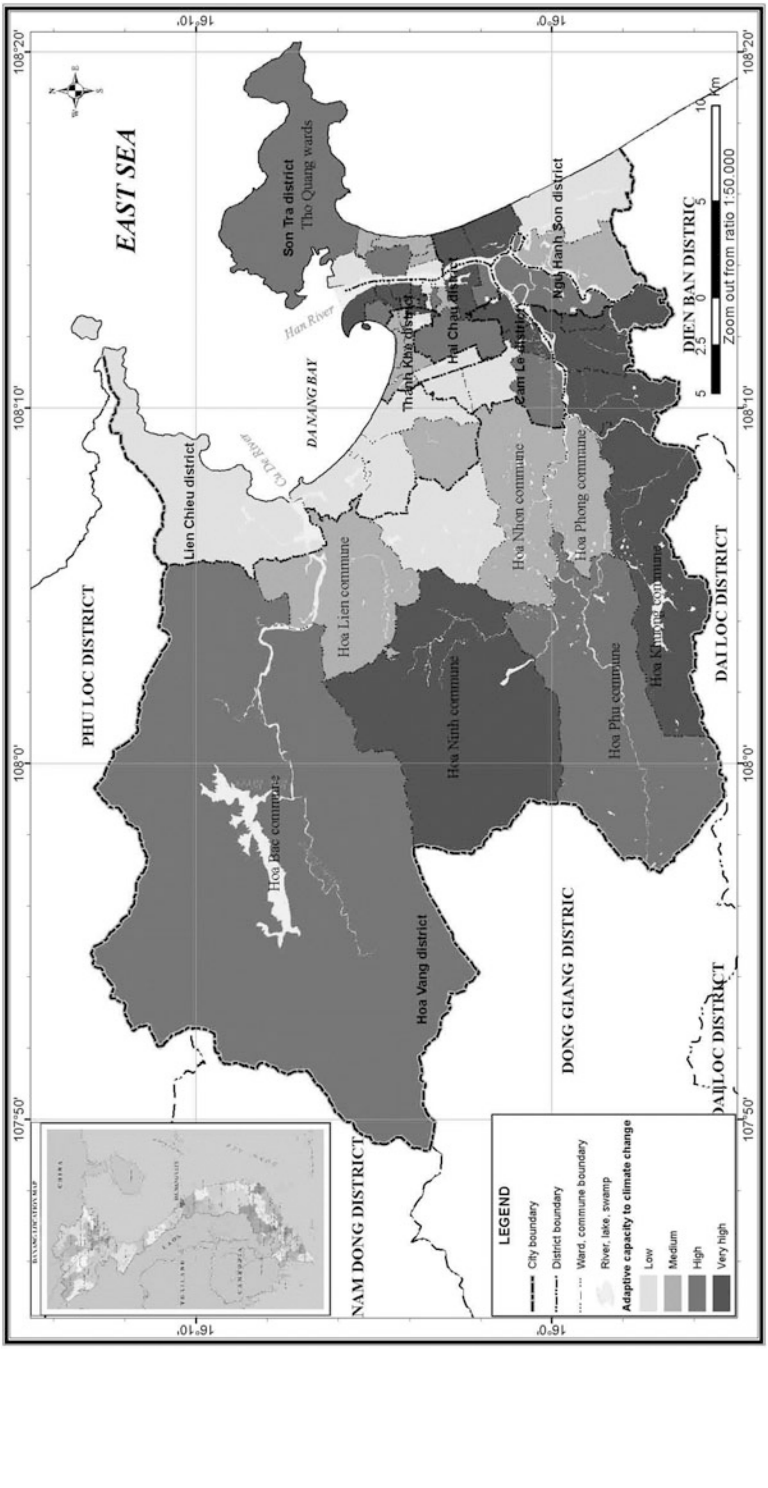

Fig. 4.4 Adaptive capacity to climate change of the communes in Da Nang city

capacity to climate change of suburban district was highly correlated with the natural resilience, such as geomorphological characteristics and natural resources. The present results demonstrated that increasing resilience in the suburban areas based on the natural resilience is more efficient than relying on the development of social resilience. However, social resilience plays a crucial role in hazard mitigation and adaptation in the urban areas.

4.5 Conclusions and Proposal of Response Measures for Enhancing Resilience to Climate Change in Da Nang City

This chapter reviewed the occurrence of climate change impacts in Da Nang city, a coastal urban area of Vietnam. Results have demonstrated that the climate variability and climate-related disasters (typhoon, floods, saline intrusion, etc.) tend to increase in recent years in Da Nang city and have happened with an alarm rate. Therefore, the urban government should invest effective and timely early warning systems at the most vulnerable and high danger level areas to disasters and climate change. According to the future climate change stimuli, Da Nang city should incorporate climate change adaptation and resilience into planning and developing policies and strategies. The climate change adaptation activities should consider the present and future impacts of climate variability and the climate-related disasters. The city should implement the proactive prevention and effective response to climate change based on assessment of risk, vulnerability, and adaptive capacity to climate change. The government should protect the diversification of natural environment, including natural ecosystems and resilient areas to climate change. This would contribute to increase the resilience of natural environments and ecosystems. Finally, the urban governance needs to focus to resolve the social equity and to enhance the transformative capacity from climate change to sustainable development opportunities, for example, promoting investigation to renewable energy sources, green economy, and priority in developing science and technology for mitigating climate change.

Acknowledgments This research is funded by the Vietnam National University (VNU), Hanoi, under project number QG.16.18.

References

ACCCRN (2009) Hazard, capacity & vulnerability assessment. Technical report, Asian Cities Climate Change Resilience Network

Adger WN (2000) Social and ecological resilience: are they related? Prog Hum Geogr 24:347–364

Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-ecological resilience to coastal disasters. Science 309:1036–1039

Coumou D, Rahmstorf S (2012) A decade of weather extremes. Nat Clim Chang 2(7):491–496
Cruz R, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B, . . . Ninh NH (2007) Asia. Climate change 2007: impacts, adaptation and vulnerability. In: ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, CE Hanson (eds) Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change, vol 28. Cambridge University Press, Cambridge, pp 469–506. Accessed February 2013
Cutter SL (2013) Building disaster resilience: steps toward sustainability. Challenges Sustain 1:72–79
Da Nang People's Committee (2011) Environmental status of Da Nang City during 2005–2010 with a vision to 2015
Da Nang People's Committee (2012) Response to climate change and sea level rise plans of Da Nang city towards 2020
Folke C (2006) Resilience: the emergence of a perspective for social–ecological systems analyses. Glob Environ Chang 16:253–267
General Statistics Office of Vietnam (2015) https://www.gso.gov.vn. Accessed 10 Jan 2016
Hallegatte S, Green C, Nicholls RJ, Corfee-Morlot J (2013) Future flood losses in major coastal cities. Nat Clim Chang 3(9):802–806
Hasegawa T, Fujimori S, Takahashi K, Yokohata T, Masui T (2016) Economic implications of climate change impacts on human health through undernourishment. Clim Chang:1–14
IPCC (2007) Fourth assessment report: climate change 2007 (AR4). Intergovernmental panel on climate change. Geneva, Switzerland, p 104
IPCC (2012) In: Field CB et al (eds) Managing the risks of extreme events and disasters to advance climate change adaptation – a special report of working groups I and II of the intergovernmental panel on climate change. Cambridge University Press, Cambridge/New York
Leichenko R (2011) Climate change and urban resilience. Curr Opin Environ Sustain 3:164–168
Ministry of Natural Resource and Environment (MONRE) (2012) Climate change and sea level rise scenarios for Vietnam. Natural resources-environment publishing house, Hanoi. 112p. (In Vietnamese)
Nhuan MT, Tue NT, Hue NTH, Quy TD, Lieu TM (2016) An indicator-based approach to quantifying the adaptive capacity of urban households: the case of Da Nang City, Central Vietnam. Urban Clim 15:60–69
Olsson P (2003) Building capacity for resilience in social-ecological systems. Doctoral dissertation. Stockholm University
Reed S (2013) Climate resilience case study: Da Nang City, Vietnam. Institute for Social and Environmental Transition-Vietnam, Da Nang city
Tuan TH, Tran P, Hawley K, Khan F, Moench M (2015) Quantitative cost-benefit analysis for typhoon resilient housing in Da Nang city, Vietnam. Urban Clim 12:85–103
UN (2015) http://www.un.org/sustainabledevelopment/climate-change-2/
Wu X, Lu Y, Zhou S, Chen L, Xu B (2016) Impact of climate change on human infectious diseases: empirical evidence and human adaptation. Environ Int 86:14–23

Chapter 5
Traditional Farmers' Adaptation Strategies on Climate Change of Different Environmental Conditions in Yogyakarta Province, Indonesia

Irham, Osamu Saito, Hideyuki Mohri, Gilang Wirakusuma, Fatkhiyah Rohmah, and Hani Perwitasari

Abstract Adaptive capacity has become one of the important issues in explaining societal aspects of climate change (Hinkel 2011). Therefore, understanding farmers' adaptation strategy on climate change is seen as key to address agri-environmental challenges. The objectives of the study are (1) to understand the farmers' perception on climate change, (2) to identify various adaptation strategies of the farmers in coping with climate change, (3) to find the most suitable adaptation strategy for farmers, and (4) to analyze the socioeconomic factors affecting the farmers' decision in using the adaptation strategy. The results of the study show that very few farmers know about global warming and climate change, especially in unfavorable upland area. But the farmers understand some indications of the existence of climate change, such as increase of temperature, unstable rainfalls, and unpredictable rainy and dry seasons during the last 20 years. Most of the farmers agreed that the climate change has caused farm production decrease and sometimes crop failure. Water shortage and pest outbreaks are among consequences of the climate change experienced by the farmers. The study also shows that applying terracing system, cultivating land by contour lines, utilizing organic

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K. Takeuchi et al. (eds.), *Resilient Asia*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56597-0_5

materials, applying multi-cropping pattern, crop rotation, and food storage are strategies mostly adopted by the farmers in order to cope with climate change. The result of analysis also shows that livestock ownership, drought experience, and water shortage are among factors that influence significantly their adaptation strategy decision. The study suggests the need to improve the knowledge of the farmers with respect to climate change and its impacts through extension services. It is recommended for the local government to increase the farmer's ownership of livestock in coping with the climate change by introducing revolving fund scheme. The study also suggests to develop more weirs particularly in the upland area to solve the problem of drought and water shortage.

Keywords Climate change · Environmental condition · Farmers' perception · Adaptation strategy · Yogyakarta province

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5.1 Introduction

Climate change has severe impacts in developing countries, since they are very much dependent on natural resources as the sources of food, water, and shelter (FAO 2010). As a country which lies on the equator, climate becomes an important determinant for food production in Indonesia. When climate change threatens the agriculture sector, then the food production system of the country is also threatened. Climate change affects the agricultural sector in many aspects including water resources, agricultural infrastructure, agricultural production systems, food security, and ultimately the welfare of farmers and their families.

Many studies on the impact of climate change on biological production, water availability, temperature, etc. have been done (Devkota and Gyawali 2015; Bhatt et al. 2014; Lobell et al. 2011; Felkner et al. 2009; Barrios et al. 2008; Shafiq and Kakar 2007). Although these are equally important, limited studies have been carried out on how traditional farmers particularly in developing countries understand climate change and how they cope with the effects of climate change (Olsson 2003; Irham 2012). Since most of the traditional farmers have limited knowledge on climate change, understanding the perception of farmers on climate change (Fosu-Mensah et al. 2010), their adaptation strategies (Indonesian MOA 2011), as well as the factors that influence the adaptation strategies become very important.

Hasan and Nhemachena (2008) provide us with a good lesson on the perception of farmers on climate change. They showed that out of 8,208 respondents, 50% of them feel that temperature is getting warmer/hot, another 50% feel the water precipitation is decreasing, 33% expressed confidence that the rainy season has changed, and 16% said there were more frequent droughts. Of course, the perceptions of farmers on climate changes are varied depending on areas where they live and their knowledge. In many cases, the activities of farmers through the cultivation methods contributed to the increase in greenhouse gases and in turn cause climate change.

Studies conducted by Maddison (2007) in collaboration with the World Bank in several African countries showed that the majority of farmers perceive that the climate gets hotter, the rain is getting difficult to predict, and the duration of the rainy season is getting shorter. Tomkins and Adger (2004) identifies climate change in different forms such as: (1) slow changes in mean climate conditions, (2) increased interannual and seasonal variability, (3) increased frequency of extreme events, and (4) rapid climate change causing catastrophic shifts in ecosystems.

Climate change adaptation is one of the policy options to reduce the negative impacts of climate change (Adger et al. 2003). Adaptation to climate change refers to adjustment in natural or human systems in response to climatic stimuli from the actual or expected climate change effects (IPCC 2001, 2007). Different societies provide different types of adaptability in coping with the consequences of climatic changes. Those types of local adaptation systems are examples of how societies use their local wisdom in dealing with vulnerable situations by developing a symbiotic interaction between ecosystems and humans (Takeuchi 2012; Irham 2012).

Theoretically, there is a strong relation between adaptation, resilience, and sustainability. Resilience is the ability to persist and adapt in order to promote sustainability. But it should be noted that resilience and sustainability need proactive action to avoid vulnerability and to provide ecological integrity into the future (Hahn et al. 2009). Enhancing resilience means increasing communities' adaptability while reducing vulnerability, risk, and uncertainty.

Acceleration of economic development has a very strong relation with the increase in vulnerability. Our experience from the field shows that unfavorable rural areas provide more opportunities to find key lessons for resilience compare to that of favorable areas where economic development to some extent has an adverse effect on traditional wisdom. Therefore, our study in less favorable upland area in Gunung Kidul District comparing with that of unfavorable area in Sleman District of Java, Indonesia, is a challenge to prove the above phenomenon.

This study contributes to understanding how climate change can be defined in different perspective by investigating the farmers' perception on climate change. The objectives of this study are (1) to understand the farmers' perception on climate change at different environmental conditions, (2) to find various adaptation strategies of the farmers in coping with climate change, (3) to find the adaptation variables that are suitable for the farmers' adaptation strategy, and (4) to analyze the socioeconomic factors affecting the farmers' decision in using adaptation strategy.

5.2 Materials and Methods

5.2.1 Study Area

The study was conducted in two districts of Yogyakarta province, namely, upland Gunung Kidul District representing unfavorable areas and lowland Sleman District representing favorable areas. Jati Hamlet of Giricahyo Village in the district of Gunung Kidul and Somokaton Hamlet of Margokaton Village in Sleman District were selected as study sites. Jati Hamlet is located close to the coastal area approximately 30–40 km south of city center of Yogyakarta, whereas Somokaton Hamlet is located about 10 km north of the city center with better accessibility to the city compared to that of Jati Hamlet (Fig. 5.1).

The topography of Jati Hamlet region is dominated by karst with the altitude of 100–400 m above sea level. The region has the lowest rainfall compared with other districts with less fertile agricultural land. The average daily temperature is 27.7 °C. The average rainfall in this region is 1720 mm per year with the number of rainy days on average 115 days annually. Irrigated paddy fields dominate the area of Somokaton Hamlet with altitude of less than 100 meter above sea level. The average annual rainfall is 2345 mm, with the average daily temperature 25.5 °C.

Fig. 5.1 Location of the study

5.2.2 Data Used and Method of Analysis

Data were collected by interviewing 32 farmers in Jati Hamlet of Gunung Kidul District and another 32 farmers in Somokaton Hamlet of Sleman District. The farmers were interviewed, and the study sites were similar to those used in the Joint Research Project "Toward Harmonization between Development and Environmental Conservation in Biological Production," JSPS-DGHE Core University Program in Applied Biosciences, the University of Tokyo, IPB, and Gadjah Mada University (1998–2008). Interviews were carried out in order to get information on farmer's perception about climate change, adaptation strategy of the farmers in coping with climate change, and the socioeconomic condition of the farmers.

To understand the farmers' perception on climate change at different environmental condition, cross tabulation analysis was applied by comparing the farmers' perception between those in unfavorable and favorable areas. It was expected that the farmers with different environmental condition have different experience in coping with climate change, and therefore they have different perceptions and strategies. Simple statistical t-test was used to test their significant difference.

To analyze the correlation between farmers' adaptation strategies and variety of adaptation behavior variables, *chi-square* (X^2) test was introduced by using Eq. (5.1). This method is used to test significant differences between the number of observations for adaptation strategy and certain adaptation behavior variable.

$$X^2 = \sum_{i=1}^{k} \frac{(Oi - Ei)^2}{Ei} \tag{5.1}$$

Oi = *Observation value* of ith variables
Ei = *Expected value* of ith variables
$\sum_{i=1}^{k}$ = The number of observed categories

To analyze the socioeconomic factors affecting farmers' adaptation strategy, logistic regression model was utilized. Logistic (logit) model is useful when the dependent variable has only two possible options (using adaptation strategy or otherwise), and therefore the value is bound to 1 and 0 (Ramanathan 1995) as formulated in Eq. (5.2).

$$Y_i{}^* = \beta_1 + \beta_2 X + \mu, Y = 1[Y^* > 0] \tag{5.2}$$

Y_i* is unobserved variable. In this case Y_i* is the possibility of farmers using adaptation strategy in coping with climate change. Y_i* is a dummy variable since the possible value of Y_i* is 1 and 0 which is defined as follows:

$Y_i = 1$, if $Y_i^* > 0$
$Y_i = 0$, if $Y_i^* \leq 0$

If P_i is the possibility of farmers using adaptation strategy $Y_i^* > 0$ then:

$P_i = \text{Prob}\ (Y_i = 1)$
$P_i = \text{Prob}\ (Y_i{*} > 0)$
$P_i = \text{Prob}\ (\beta_1 + \beta_2 X_{i2} + \mu_\text{i} > 0)$
$P_i = \text{Prob}\ (\mu_i > -(\beta_1 + \beta_2 X_{i2}))$

By using logistic function, then Pi is defined as in Eq. (5.3) and (5.4):

$$Pi = \frac{1}{1 + E(-\beta 1 + \beta 2Xi2 + \mu)} \tag{5.3}$$

While 1-*Pi* can be written as follows:

$$1 - Pi = \frac{Exp(-(\beta 1 + \beta 2Xi2 + \mu))}{1 + Exp(-(\beta 1 + \beta 2Xi2 + \mu))} \tag{5.4}$$

In log form, the logit function can be written as in Eq. (5.5):

$$\text{Ln}\frac{P}{1 - Pi} = \beta_1 + \beta_2 \text{X}_{\text{i2}} + \mu \tag{5.5}$$

Therefore, in order to estimate the socioeconomic factors of farmers' adaptation strategy, the estimate equation can be written as in Eq. (5.6):

$$\ln \frac{P}{1 - Pi} = \begin{array}{l} \beta \text{X}_1 + \beta \text{X}_2 + \beta \text{X}_3 + \beta \text{X}_4 + \beta \text{X}_5 + \beta \text{X}_6 \\ + \beta \text{D}_7 + \beta \text{D}_8 + \beta \text{D}_9 + \beta \text{D}_{10} + \mu \end{array} \tag{5.6}$$

where:

P: Probability of using adaptation strategy
1-P_i: Probability of not using adaptation strategy
X_1: Age of farmers (years)
X_2: Number of family members
X_3: Education level(years)
X_4: Cultivated land size (ha)
X_5: Livestock production (Rp million)
X_6: Income (Rp juta)
D_{fg}: Dummy participation in farmer's group
D_{cf}: Dummy of experienced crop failure
D_{df}: Dummy of drought frequency
D_{pi}: Dummy of permanent irrigation
β_1: Coefficient
μ: Residual

5.3 Results and Discussion

5.3.1 Farmers' Perception on Climate Change

Since there is a close connection between climate change and the so-called global warming (temperature increase), it is important to know the traditional farmers' knowledge on both aspects. Table 5.1 shows that although only few farmers in favorable areas understand about global warming (temperature increase) (25%), much less farmers in unfavorable areas know regarding global warming (6%). The number of farmers who know climate change in both areas is slightly higher. According to the farmers, the knowledge about climate change was obtained either from television or farmer's group. Since most of the farmers have little knowledge about global warming and climate change (75–94%), it is certainly a challenge for the local government and relevant agencies to further disseminate both issues particularly the impacts on their farming activities.

According to the farmers' perceptions, increase in temperature, erratic rainfall, increase in drought frequency, and unstable planting seasons are symptoms related to climate change. By using those indicators, Table 5.2 shows that the farmers in both areas are aware that climate change has been taking place during the last 20 years. As indicated in Table 5.2, majority of farmers in both areas have similar awareness and experiences about the increase in temperature (about 80%) and erratic rainy season (about 90%). Table 5.2 also indicates that only few farmers (less than 20%) experienced higher frequency of drought in both unfavorable and favorable areas. It seems that droughts were not frequent in both areas. Both areas also experienced planting season instability; however, the farmers in the

Table 5.1 Farmers' knowledge about global warming and climate change

Farmers' perception	Percentage (%)		Sig
	Sleman	Gunung Kidul	
Know about global warming	22	6	0,075*
Know about climate change	25	13	0,207 ns

Source: Analysis of Primary Data, 2013
* Significant at 10%

Table 5.2 Farmers' perception about climate change during the last 20 years

Number of farmer who felt:	Percentage (%)		Sig
	Sleman	Gunung Kidul	
Temperature increase	84	81	0,745 ns
Erratic rainfall	94	91	0,648 ns
Increasing drought frequency	19	18	0,002***
Unstable planting seasons	69	84	0,030**

Source: Analysis of Primary Data, 2013
*** Significant at 1% ** Significant at 5%

unfavorable area had more severe condition compared to those in the favorable area (significant at 5%). Under this condition, during the rainy season, the water becomes excessive, while in the dry season, it tends to be much less available.

The impact of climate change cannot be directly perceived because climate change is a long process, and also the traditional farmers have no scientific knowledge about climate change. Therefore, a knowledge about farmers' perceptions is very important to understand the impact of climate change. Table 5.3 shows that most of the farmers noticed that their farm production declined, and they had even experienced crop failure due to the climate change. Less crop production has been similarly experienced by the farmers in both unfavorable and favorable areas, but the farmers in the unfavorable area suffer more crop failure than that of in favorable area (Table 5.3).

Less crop production and crop failure are strongly related with other impacts of climate change experienced by the farmers such as drier farmland, difficulty in cultivating the land, difficulty to start planting, as well as decrease volume of water source (Table 5.3). In this case, the farmers in unfavorable area (upland) experienced more severe impacts than those in the favorable area (lowland). This is understandable because the upland areas of Gunung Kidul District is entirely dependent on rainfall for water availability, while lowland Sleman District has a permanent irrigation system supported by Mataram canal. Only in terms of pest infestation the favorable area suffers more than the unfavorable area. This result is consistent with the findings of Alimin (2011) that the effects of climate change were able directly or indirectly to stimulate the growth of plant pests which could cause the decline of agricultural and plantation crops.

5.3.2 *Farmers' Adaptation Strategy to Climate Change*

Some adaptation strategies were adopted by the farmers in coping with the impact of climate change on crop cultivation, land conservation, and food stock.

Table 5.3 Farmers' perception about the impacts of climate change on farming

Perception	Percentage (%)		Sig
	Sleman	Gunung Kidul	
Crop production has decreased	75	69	0,585 ns
Crop failure are frequent	81	59	0,031**
Agricultural land are getting drier	34	75	0,000***
Agricultural land are more difficult to cultivate	44	72	0,023**
Difficult to determine the start of planting season	69	84	0,030**
Decrease volume of water bodies (source)	44	66	0,081*
Increase in plant pests attack	84	50	0,003***

Source: Analysis of Primary Data, 2013
*** Significant at 1% ** Significant at 5% * Significant at 10%

Comparing how those practices were implemented in both study sites is also important to understand their behavior; hence a simple statistical test was applied.

In terms of cultivation technique, organic or semi-organic farming becomes one of the farmers' strategy choices by adding organic material or manure as fertilizer. However, not all farmers in the study area have adopted organic farming. Less than half of the farmers in Sleman applied this strategy compared to more than 80% of farmers in Gunung Kidul who used such strategy. This is due to the fact that livestock rearing becomes part of their life, so that most farmers in Gunung Kidul District find easier to get organic matters.

This study also found that 88% (majority) of farmers in Gunung Kidul District implemented multi-cropping and intercropping patterns (Table 5.4). This is important, given the intercropping system will give farmers more income sources from various crops produced. Moreover, intercropping also reduce the risk of crop failure, unlike farmers in Sleman District where most of them just grow rice through the years. Unfortunately, few farmers in both study sites (25% or less) applied water-saving cultivation techniques which is very important in adaptation strategy toward climate change.

Furthermore, with respect to how farmers cope with the impact of climate change, the traditional farmers intensify land conservation practices. Some respondents in both study areas intensified integrated livestock-farming activities. The farmers raise more livestock and use manure from the livestock on agricultural land as fertilizer. A similar land conservation practice also applied in Gunung Kidul and Sleman where the farmers made use of straw and crop residues (after harvest) for composting to improve soil fertility and reduce the use of chemical fertilizers. Other conservation practices were also implemented by farmers such as making terraces on their farmland, cultivating land by contour lines, and planting cover crops on terraces in order to reduce runoff to avoid soil erosion. This result is in line with the findings of Gallart et al. (1994), Chow et al. (1999), and Delgado and Gantzer (2015). This kind of practices is more observable in the upland area of Gunung Kidul District (Table 5.4).

The farmers also combined the aforementioned strategies by starting planting in accordance with season, crop rotation including rotation with legumes, not only to enrich the soil fertility but also related with the crops suitability for the current season. For the farmers in favorable irrigated area (Sleman District), maintaining irrigation system becomes their choice of strategy in coping with climate anomaly.

Table 5.4 Farmers' adaptation strategies in crop cultivation management

Adaptation strategy	Percentage (%)		Sig
	Sleman	Gunung Kidul	
Applying organic farming	44	84	0,001***
Adding organic material to land	56	100	0,000***
Multi-cropping patterns	19	88	0,000***
Water-saving cultivation techniques	19	25	0,597 ns

Source: Analysis of Primary Data, 2013
*** Significant at 1%

Although only few respondents have utilized drought-resistant crop varieties in both study sites, this strategy will be a potential one in coping with climate change in the future (Table 5.5).

Postharvest strategy by households in rural areas such as food stock management and food combination could not be separated from the farming strategy in coping with climate change. In terms of food management, almost all farmers (97%) in Gunung Kidul District keep in stock more than half of their harvested rice although the stock of the harvested rice in one season is not enough until the next harvest. In Sleman District, on the other hand, only 53% farmers store their yields because a half of farmers in this district sell their crops as soon as harvested. Although in small numbers (28% in Gunung Kidul and 6% in Sleman) (Table 5.6), some farmers also combine rice especially with the cassava or corn to save on food costs (Table 5.7). This effort is in line with the government regulation No. 15/Permentan/OT.140/2/2013 regarding diversification program improvement and community food security (Indonesian MOA 2012).

In order to analyze the correlation between farmers' adaptation strategies and a variety of adaptation behavior variables, chi-square test was used. This method is used to test significant differences between the number of observations for adaptation strategy and certain adaptation behavior variable. The results of the analysis show that those adaptation behavior variables (organic/semi-organic farming, water-saving cultivation technique, multi-cropping patterns, crop rotation, using drought-resistant varieties, and harvested crop stocking) have significant correlation with adaptation strategy (Table 5.7). This implies that those variables can be used by farmers as means of adaptation.

5.3.3 Socioeconomic Factors Affecting Farmers' Adaptation Strategies

The assessment of the socioeconomic impacts of climate change at household level particularly farm households has been the high concern of FAO (2008), FAO (2015), and IPCC (1995). This part is to test what socioeconomic factors affect the farmers' adaptation strategy toward climate change. The result of analysis shows that only three factors affect significantly farmers' adaptation strategies, namely, livestock production, drought frequency, and having permanent irrigation (Table 5.8). Education level of the farmers is actually expected to have a significant and positive effect on their adaptation strategy expecting the higher the education level, the higher possibility of farmers to use adaptation strategy. Unfortunately, this is not the case in the study areas since most of the farmers are in the low education level (mostly elementary school).

Livestock production is understandable to influence the farmers' adaptation strategy. This is due to the fact that having enough livestock enables farmers to make adaptation with climate change by using organic material from the manure.

Table 5.5 Farmers' adaptation strategies in land conservation

Adaptation strategy	Percentage (%)		Sig
	Sleman	Gunung Kidul	
Integration livestock with farming	25	22	0,000***
Using straw for compost	34	14	0,450 ns
Using crop residues as fertilizer	59	15	0,324 ns
Making terrace on land	13	100	0,000***
Cultivate land by contour lines	9	100	0,000***
Planting cover crops on terraces	19	23	0,000***
Start planting in accordance with season	53	32	0,000***
Crop rotation	25	29	0,000***
Crop rotation with legumes	16	28	0,000***
Maintaining irrigation	63	8	0,002***
Using drought-resistant varieties	13	12	0,021***

Source: Analysis of Primary Data, 2013
*** Significant at 1%

Table 5.6 Farmers' adaptation strategies in household food management

Adaptation strategy	Percentage (%)		Sig
	Sleman	Gunung Kidul	
Store more of the farm produce	53	97	0,000***
Combining staple foods	6	28	0,021**

Source: Analysis of Primary Data, 2013
*** Significant at 1% ** Significant at 5%

Table 5.7 Correlation between adaptation strategy and adaptation behavior variables

Indicators	Variables	*P-value*	$\alpha = 5\%$
Adaptation strategies	Organic farming	0,000	0,05
	Water-saving cultivation	0,001	0,05
	Multi-cropping patterns	0,000	0,05
	Crop rotation	0,000	0,05
	Using drought-resistant varieties	0,003	0,05
	Store stock yields	0,000	0,05

Source: Analysis of Primary Data, 2013

By this way, soil fertility is maintained, and enough food production is more ensured to cope with the climate change.

Based on the farmers' perception, drought frequency is strongly related with climate change. Lack of water availability becomes a serious problem in farming activities particularly during long dry season. This variable positively affects farmers' adaptation strategies. It means that when the drought frequency increases, the probability of using adaptation strategies also increase, more particularly in less favorable area of Gunung Kidul District compared to that of Sleman District.

Table 5.8 Factors affecting farmers' adaptation strategies

Variable	Regression coefficients	Wald/t-calc	Sig.
Age of farmers	0.031	1.272	0.259
Number of family members	−0.364	1.822	0.177
Education level	−0.013	0.016	0.899
Cultivated land size	0.423	0.339	0.561
Livestock production	0.863***	7.074	0.008
Income	0.004	0.027	0.869
Dummy participation in farmer's group	−0.555	0.473	0.492
Dummy crop failure	−0.066	0.006	0.937
Dummy drought frequency	2.265***	6.852	0.009
Dummy permanent irrigation	−1.648*	3.717	0.054

$X^2_{(1;0.05)}$: 3841
$X^2_{(1;0.1)}$: 2705
*** Significant at 1%
* Significant at 10%

Lack of water availability will affect crop production. The existence of permanent irrigation could be a good predictor to explain probability of farmers' adaptation strategies. When water is available continuously, farmers will have less effort to do some adaptation strategies on climate change. The result of the analysis shows that permanent irrigation (dummy) has a negative and significant effect on adaptation strategy, meaning that the farmers with permanent irrigation have lower probability to use the adaptation strategy in coping with climate change. This is consistent with the earlier analysis where the farmers in Sleman District with a better irrigation system experienced much less severe condition in coping with climate change compared to that of in unfavorable Gunung Kidul District.

5.4 Conclusions and Recommendations

5.4.1 Conclusions

1. Since most of the farmers have little knowledge about global warming and climate change, there is a need to improve the knowledge of the farmers related to climate change and its impacts.
2. Intensifying integrated livestock-farming system is one of the best adaptation strategies in coping with climate change to ensure the sustainability farming and rural livelihood.
3. To avoid decline crop production and crop failures, developing more weirs is badly needed as an adaptation strategy to climate change particularly in the upland area due to the frequent drought and water shortage.

4. With respect to household food management, storing more of the farm produce and combination of staple foods are effective strategy to cope with climate change.

5.4.2 Recommendations

1. The study suggests to improve the knowledge of the farmers with respect to climate change and its impacts through extension services.
2. It is recommended for the local government to increase the farmer's ownership of livestock in coping with the climate change by introducing revolving fund scheme.
3. The study also suggests to develop more weirs particularly in the upland area to solve the problem of drought and water shortage.
4. Food diversification programs should be developed with the aim to reduce the dependency on a single agricultural commodity especially in coping with weather anomaly due to climate change that may cause crop failure.

References

Adger WN, Huq SK, Brown D, Conway HM (2003) Adaptation to climate change in the developing world. Progress in development studies. Asian Development Bank Institute, Japan

Alimin (2011) Dampak Perubahan Iklim Terhadap Serangan Organisme Pengganggu Tumbuhan (OPT) Tanaman Perkebunan (Impacts of climate change towards the outbreak of plantation pests). Accessed from http://ditjenbun.deptan.go.id/perlindungan/index.php? option=com_conte nt&view=article&id=133:dampak-perubahan-iklim-terhadap-serangan-organisme-pengganggu-tumbuhan-opt-tanaman-perkebunan&catid=15:home>Friday, 24 Mei 2013–23:02:18 WIB

Barrios S, Bazoumana O, Eric S (2008) The impact of climatic change on agricultural production: is it different for Africa? Food Policy 33(4):287–298

Bhatt D, Maskey S, Babel MS, Uhlenbrook S, Prasad KC (2014) Climate trends and impacts on crop production in Koshi River Basin of Nepal. Reg Environ Chang 14(4):1291–1301

Chow TL, Rees HW, Daigle JL (1999) Effectiveness of terraces grassed waterway systems for soil and water conservation: a field evaluation. J Soil Water Conserv 54(3):577–583

Delgado JA, Gantzer CJ (2015) The 4Rs for cover crops and other advances in cover crop management for environmental quality. J Soil Water Conserv 2015 70(6):142–145

Devkota LP, Gyawali DR (2015) Impact of climate change on hydrological regime and water resources management of the Koshi River Basin. Nepal J Hydrol: Reg Stud 4:502–515

FAO (2008) The assessment of the socioeconomic Impacts of climate change at household level and policy implications, Agricultural Development Economics Division, FAO, Rome, Italy

FAO (2010) Pacific food security toolkit, building resilience to climate change, root crop and fishery production. Electronic Publishing Policy and Support Branch Communication Division Food and Agriculture Organization of the United Nations Viale delle Terme di Caracalla 00153 Rome, Italy

FAO (2015) Socio-economic implications of climate change for tea producing countries. FAO Intergovernmental Group on Tea A Subsidiary Body of the FAO Committee on Commodity Problems (CCP), Rome, Italy

Felkner J, Tazhibayeva K, Townsend R (2009) Impact of climate change on rice production in Thailand. Am Econ Rev 99(2):205–210

Fosu-Mensah BY, Vlek PLG, Manschadi AM (2010) Farmers' perceptions and adaption to climate change: a case study of Sekyedumase District in Ghana. Centre for Development Research, University of Bonn, Jerman

Gallart F, Llorens P, Latron J (1994) Studying the role of old agricultural terraces on runoff generation in a small Mediterranean mountainous basin. J Hydrol 159(1–4):291–303

Hahn MB, Riederer AM, Foster SO (2009) the livelihood vulnerability index: a pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique

Hasan R, Nhemchena C (2008) Determinants of African farmers' strategies for adapting to climate change: multinomial choice analysis. Afr J Agric Resour Econ (AfJARE) 2

Hinkel J (2011) Indicators of vulnerability and adaptive capacity: towards a clarification of the science-policy interface. Global Environ Chang 21:198–208

Indonesian MOA (2011) Pedoman Umum Adaptasi Perubahan Iklim Sektor Pertanian (Ministry of Agriculture: General Guidelines of Climate Change Adaptation in Agricultural Sector). http://www.litbang.deptan.go.id/download/one/132/file/pedum-adaptasi.pdf

Indonesian MOA (2012) Peraturan Menteri Pertanian Republik Indonesia. Regulation of Ministry of Agriculture, Republic of Indonesia. Accessed from http://perundangan.deptan.go.id/admin/file/Permentan-14-12.pdf

IPCC (1995) Economic and social dimension of climate change, second assessment report. Intergovernmental panel on climate change, Cambridge, United Kingdom, and New York

IPCC (2001) Climate change 2001: impacts, adaptation, and vulnerability (Technical summary of report of working group II of the Intergovernmental panel on climate change). www.ipcc.ch

IPCC (2007) Climate change 2007 – impacts, adaptation and vulnerability. In: Parry ML, OF Canziani, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of working group II to the fourth assessment report of the IPCC. Cambridge University Press, Cambridge

Irham (2012) Building resilience with common capital: Indonesian case. A paper presented in the first workshop building resilience with common capital, managing shared resources: meeting the challenges of a rapidly modernizing world under climate and ecosystems change, Tokyo 23–25 January

Lobell DB, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. Science 333(6042):616–620

Maddison D (2007) The perception of and adaptation to climate change in Afrika. Centre for environmental economics and policy in Africa, University of Pretoria. CEEPA discussion paper No. 10

Olsson P (2003) Building capacity for resilience in socialecological systems. A dissertation, department of systems ecology Stockholm University, S-10691 Stockholm, Sweden

Ramanathan R (1995) Introductory econometrics with application, 3rd edn. Harcourt College Publishers, New York

Shafiq M, Kakar MA (2007) Effects of drought on livestock sector in Balochistan Province of Pakistan. Int J Agric Biol 9(4):657–665

Takeuchi K (2012) Sub-global assessment of *Satoyama* and *Satoumi* in Japan and Its contributions to *Satoyama* initiative. A paper presented in the first workshop building resilience with common capital, managing shared resources: meeting the challenges of a rapidly modernizing world under climate and ecosystems change, Tokyo 23–25 January

Tomkins EL, Adger WN (2004) Does adaptive management of natural resources enhance resilience to climate change? Ecol Soc 9(2):10

Chapter 6
Ecosystem Services of Traditional Homegardens in South and Southeast Asia

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Abstract Among homegarden research, few studies assess and compare ecosystem services provided by different systems. This chapter discusses the similarity and differences in structural characteristics, functions, ecosystem services, and biodiversity of different homegarden systems across Indonesia, Sri Lanka, and Vietnam. A case study on Sri Lanka highlights how we can apply ecosystem service

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K. Takeuchi et al. (eds.), *Resilient Asia*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56597-0_6

assessments to better understand drivers of changes for these homegarden systems and adapt them to economic, social, and environmental changes to continue to enhance rural livelihoods.

Keywords Homegardens · Ecosystem assessment · Ecosystem services · Agrodiversity · Adaptation

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6.1 Introduction

A homegarden is a small-scale agricultural system that provides various goods and services, including secondary sources of food and income, and often also mimics aspects of natural forest systems (Hoogerbrugge and Fresco 1993). Soemarwoto and Christanty (1985) define a homegarden as *a land-use system with a structure resembling a forest that combines the natural architecture of a forest with species fulfilling the social, economic, and cultural needs of people*. Soemarwoto and Conway (1992) also define homegardens as agro-socio-ecological systems with plants and animals as an integral part of the system along with humans. They produce a variety of fruits, vegetables, fibers, and non-timber products to support family diet and provide additional income. Homegardens are distributed around the world, but are predominantly a tropical phenomenon, considered among the oldest type of land-use system after shifting cultivation (Kumar and Nair 2004).

Past research on homegardens has typically focused on functional, ecological, or structural components specific to a study area (e.g., Phong et al. 2010; Kehlenbeck et al. 2007; Abdoellah et al. 2006; Phong et al. 2006; Ueda 1996; Soemarwoto and Conway 1992; Karyono 1981; Wiersum 1977). Some recent research on agroforestry and traditional production systems has also begun to consider the capacity of homegardens to help adapt to ecosystem and climate change-related challenges (Rao et al. 2007; Takeuchi 2010). However, the uniqueness of households and their homegardens has made it difficult to implement commonly accepted research frameworks and methods for understanding homegardens, despite their structural and functional similarities (Kumar and Nair 2004). The objective of this paper is to apply a common ecosystem services-based framework to homegarden research, including:

(a) To investigate the diversity of scale, structure, and function in homegarden systems of South and Southeast Asia
(b) To understand drivers of changes and some strategies to enhance these homegarden systems based on a case study of Sri Lanka

6.2 Methodology and Materials

6.2.1 Methodology

To evaluate the interactions between different ecosystem services provided by homegarden systems and to identify the drivers of change, the study used the Millennium Ecosystem Assessment (MA) framework (MA 2003, 2005). The framework focuses on linkages and dynamic interactions between ecosystem services and human well-being (MA 2005).

An extensive literature review examined 104 books, peer-reviewed journal articles, and conference papers (Mohri et al. 2013). The distribution of publications was diverse in terms of publication year and theme, and almost equal numbers of literature for study areas were referenced to identify components, spatial layout, temporal/spatial scales, diversity, and functions of each system by country. Additionally, field observation and professional workshops were conducted between 2011 and 2012 in each country, as shown in Table 6.1. The case study focuses on Sri Lanka to identify the role of homegardens and potential strategies to enhance homegarden systems. Two major field surveys were conducted in the Kandy area, and the northern part of Sri Lanka. Details of surveys are described later in this paper.

6.3 Traditional Homegarden Systems in Indonesia, Vietnam, and Sri Lanka

As a traditional land-use system, homegardens have evolved from prehistoric times through ancient civilizations to the modern era (Mohri et al. 2013). This study focuses on one particular kind of homegarden in three countries: the Pekarangan (Java, Indonesia), Kandyan (Sri Lanka), and VAC systems (Vietnam). Each has different characteristics reflecting their socioeconomic and geographic conditions.

Indonesia is the world's largest island nation with diverse land-use systems and bio-production systems. In this study, we focus on Pekarangan, a traditional homegarden system in Java, which is generally managed by individuals who grow various products for subsistence purpose (Wiersum 2006). Ancient records indicate the homegardens of Java originated as public space associated with temple precincts and have been attached to palaces and homes (Mohri et al. 2013).

Sri Lanka has the highest rural population among Asian nations (World Bank 2011). Kandyan homegardens play a key role to link agricultural and natural landscapes and provide a secondary source of income in the country's midlands (Pushpakumara et al. 2010). Historic evidence of gardens similar to present-day Kandyan homegardens can be found in the ancient epic Ramayana (Puri and Nair 2004; Kumar and Nair 2004). Kandyan homegardens are multi-structured plots

Table 6.1 Biophysical and socioeconomic features of homegardens in the study area

Characteristics	Javanese homegardens	Kandyan homegardens	VAC system
Location/ country	Indonesia	Sri Lanka	Vietnam
Local name	Pekarangan	Kandyan gardens	VAC system
Population density (km²)	700[1]	500–699	1.1–13.9 (person/ha)[5]
Eco-zone	Humid; medium altitude and lowlands	Humid; medium altitude	Red River Delta, tropical to subtropical; midlands, tropical and subtropical; lowlands, tropical; Mekong Delta, tropical
Rainfall (mm)	1800–2400	2000–2500	1388–1900
Altitude range (m amsl)	0–600[1]	400–1000	1–80
Temperature (°C)	22–29	24–26	26–29.5
Relative humidity (%)	Average 75	65–80 (day) and 75–90 (night)	82
Number of vertical canopy	5[1]	3–5	N/A
Dominant soil type	Reddish brown latosol to brown latosols	Reddish brown latosol to immature brown loam	North, loam and sandy loam; central, Bazan; south, alluvial clay; Mekong Delta, clay
Slope of land (%)	Varied	10–40	Varied
Land tenure	Privately owned[2]	Mainly privately owned	Privately owned (allocated by government)
Typology	Traditional and commercial		Traditional, commercial, mixed
Market orientation	Subsistence/commercial	Commercial with subsidiary subsistence	Subsistence/commercial
Net income	6.6–55.7% of total income with an average of 21.1% depending on size, family needs, and composition of homegardens[3]	30–50% of household income[4]	30–60% of family income

Adapted from Mohri et al. (2013)
Sources: [1]Fernandes and Nair (1986), [2]Wiersum (1982), [3]Soemarwoto (1987), [4]Pushpakumara et al. (2010), [5]General Statistics Office of Vietnam (2013)

established around rural homes, with a deliberate mix of indigenous and exotic species providing multiple uses and ecosystem services (Gunatilleke et al. 1993).

Vietnam is a large rice-exporting country with rapid economic growth. Changing economic policies have driven significant change in rural land-use and traditional bio-production systems, including the Vuon-Ao-Chuong system (VAC system, or Garden-Pond-Livestock pen in English, also known as traditional integrated agriculture-aquaculture, or IAA). The VAC system originated in the Red River Delta and midlands of Northern Vietnam and uses household land for various agri-aquaculture activities (Trinh et al. 2003). Implementation of the national government's Doi Moi policy in 1986 promoted the VAC system to improve and stabilize the nutritional and dietary standards of the rural poor (Luu 2001). This policy resulted in extensive coverage of integrated VAC farming across Vietnam, especially in irrigated lowlands, rain-fed uplands, and semi-urban areas (Luu 2001; Nguyen 1997; Phong et al. 2003; Phong et al. 2010).

6.3.1 Diversity in Scale, Structure, and Function of Homegarden Systems

Each homegarden has different characteristics that typically vary by geographic location, climate, culture, government policy, and socioeconomic context.

6.3.1.1 Spatial Scale: Homegarden Size

Homegarden land area differs depending upon the climate, soil type, topography, rainfall, economic activity, and culture of the study area (Mohri et al. 2013). Twenty percent of total area in Java is occupied by homegardens (Wiersum 1980; Terra 1954). Around 70% of households in the Kandy area have homegardens (Mohri et al. 2013), covering around 30% of Kandy District (Forestry Sector Master Plan 1995). Almost 44% of households now have a VAC system. The average homegarden area is 0.6 ha and 0.4 ha in Java and Kandy, respectively. In Vietnam, the VAC system has spread irregularly across the country, and so the average size is difficult to establish. Vietnam's Mekong region typically has larger homegardens and pond sizes than the northern part (Trinh et al. 2003).

6.3.1.2 Temporal Scale: Labor and Time

Homegardens require little time and labor relative to primary farming activities and are mostly maintained by household members during free time to flexible schedules. Labor time differs by size, farming intensity, number of family members, and their primary occupation (Torquebiau 1992). In Kandy, additional labor is hired for skilled operations (Jacob and Alles 1987) such as harvesting cash crops. VAC homegardens are maintained by family members.

6.3.2 Structure of Homegarden Systems

The vertical and horizontal structures of homegardens vary according to the sociocultural, economic, and ecological attributes of communities (Abdoellah et al. 2001). The Javanese and Kandyan homegardens have a complex horizontal zoning and multilevel vertical structure with a variety of species, resulting in a virtually closed canopy structure (Mohri et al. 2013). VAC systems have a simpler vertical structure. The vertical structure and main species present at different levels of the homegardens is shown in Table 6.2. A large number of species are planted in patterns unique to each homegarden to maximize space, light, water, and fertilizer requirements (Christanty et al. 1986).

6.3.3 Homegarden Functions

Wiersum (2006) highlighted the importance of livelihood conditions and household economy in determining the structure and composition of Javanese homegardens. Wiersum suggested four types of homegardens: survival, subsistence, market, and budget gardens. In Kandy, homegardens may be forested areas near the house or also include small areas of paddy in nearby valleys (McConnell 1992). In Vietnam, VAC systems vary by geography, the local commune's policy, and personal decisions (Edwards 2010). For example, coastal VAC systems focus on aquaculture, and mountainside VAC systems focus on farming and forestry (An 1997). Some VAC systems have diversified by improving commercial productivity ("improved VAC") (Edwards 2010) or incorporating forestry (RVAC) and biogas (VACB) (Ueda 1996; Zhu 2006).

6.3.4 Ecosystem Services Provided from Homegarden Systems

Homegardens are managed and modified ecosystems providing a range of services that directly benefit households but are also an important habitat for maintaining and conserving local biodiversity and source of other regulating and supporting services. The below section briefly describes the provisioning, regulating, cultural, and supporting services provided by homegardens.

Table 6.2 Vertical stratification in homegarden systems

Stratum	Height in meters (m)	Javanese homegardens	Kandyan homegardens	VAC
Level 1 – ground level	<3 m	Starchy food plants, vegetables, and spices – Languas, ganyong, *Xanthosoma*, cassava, sweet potatoes, taro, chili peppers, egg-plant, spinach, and wing bean	Vegetables, medicines, species, fruits trees, subsistence, and cash crops – okra, eggplant, beans, tea, cassava, ginger, turmeric, *Anthurium*, pineapple, and chili peppers	Flowers, medicinal plants, herbs, spices, fruits, plants in the pond (or on the banker), and vegetables
Level 2 – lower stratum	3–10 m	Fruit trees and cash crops – bananas, papayas, mango, jack-fruit, and other fruit trees; soursop, jack-fruit, pisitan guava, and mountain apple; or other cash crops such as cloves	Medicines, food staple, subsistence, and cash crops – vanilla, banana/plantain, cacao, coffee, passion fruit, betel vine	Fruits trees – *Lucuma mammosa*, orange, tangerine, grapefruit, longan, rambutan, kapok, and water apple; Bamboo, cashew, *Acacia aneura*
Level 3 – lower-middle stratum	10–15 m	Other trees for building material and fuel wood – coconut trees and other trees (e.g., *Albizia*)	Subsistence food staple, seasonal fruits, and cash crop – papaya, pepper, avocado, mangosteen, breadfruit, rambutan, citrus	Coconut, areca, bamboo, eucalypts, cajeput, and *Calophyllum inophyllum*
Level 4 – upper-middle stratum	15–25 m		Fruits, timber, medicines, cash crops – mango, bamboo, areca palm, nutmeg, clove, rubber, wild breadfruit, kitul palm	
Level 5 – upper stratum	25–30 m		Timber, cash crops, fiber, and oil seed crops – durian, talipot palm, jak, coconut palm, kapok, pepper	

Adapted from (Mohri et al. 2013)
Sources: Christanty et al. (1986), McConnell (2003), Trinh et al. (2003), An (1997)

6.3.4.1 Provisioning Services

Provisioning services are the resources supplied by homegardens to human communities, such as food, timber, fuel wood, water, and natural medicines (Mohri et al. 2013). Table 6.3 summarizes the various provisioning services and species composition found in homegardens.

Table 6.3 Provisioning services provided from homegarden systems

Provisioning services			Javanese homegardens	Kandyan homegardens	VAC system
Food	*Crops*	*Major food crops*	Rice, maize, coconuts, taro, sweet potato, cassava, yam, ganyong, spinach, wing bean, eggplant, leafy vegetables, etc.	Rice, maize, green gram, cowpeas, cassava, coconut, jackfruit, sweet potato, taro, yam, juggary, and treacle from fish tail palm	Rice, corn, sweet potato, citrus, black bean, cassava, yam, banana, coconut, jackfruit, banana, luffa, orange pomelo, longan, kumquat, spinach
		Major cash crops	Coconut, banana, orange, mango, jackfruit, papaya, guava, coffee, clove, etc.	Cacao, cloves, cocoa, coconut, banana, coffee, jackfruit, mahogany, nutmeg, pepper and other spices, teak, jak, etc.	Bamboo, pineapple, jackfruit, guava, papaya, banana, lime, orange, pomelo, lychee, pear chilies, kangkong (in the fishpond), etc [8]
	Livestock		Chickens, cows, goats, and sheep[7]	Poultry and cattle[5]: 15% of householders rear livestock[1]	Buffalo, cow, pig, chicken, duck[10]
	Aquaculture		Fishpond as a part of system	NA	Carps, robu, mrigal, mud carp, tilapia (limited number of case), soft shell turtle, frogs, snakehead fish, and catfish[8]
	Wild plant and animal food products		Weed species used for herbal medicine, roofing, vegetables, and fodder[7]	Local breeds of chicken, eggs, goat, and cow milk[4]	Guava, vegetables, longan, lychee, chilies, cassava, bamboo [9]
Fiber	*Timber*		Important source of building material, e.g., *Sandoricum koetjape*, *Crescentia cujete*, jackfruit	Supplies 48% of the total sawlog demand of the country[3]	Importance source of building materials and sawlog
	Fuel wood		Supplies 40–80% of the rural fuel wood [6], e.g., Laban, bamboo, *Muntingia calabura*	Supplies 38% of the total biomass fuel demand of the country[3]	Block wattle, *Litchi*, guava, *Melia azedarach*, *Casuarina equisetifolia*, *Mangifera*, and bamboo[8]
Genetic resources			Provides habitat for small wild animals such as birds, reptiles, and amphibians	Provides habitat for a wide range of species, from soil micro life to insects, including pollinators, and from crops, trees to mammals, birds, and other wildlife[4]	Provides habitat for small wild animals such as birds, reptiles, amphibians, and insects and plant crops

(continued)

Table 6.3 (continued)

Provisioning services	Javanese homegardens	Kandyan homegardens	VAC system
Natural medicines	Extracts from medicinal plant provide treatment against various diseases and are consumed as a way of healthy life style	Most herbs and trees are used medicinally[1], e.g., turmeric, ginger, vanilla, areca palm, clove, nutmeg, etc.	Plenty herbs and medicinal plants used medicinally such as ginger, clove, *Artemisia*, etc.
Nutrition	Supplies 18% calories and 14% proteins [2], and provides vegetable proteins, carbohydrates, vitamins, and minerals	NA	NA

Adapted from (Mohri et al. 2013)
Sources: [1]Pushpakumara et al. (2010), [2]Ochse and Terra (1937), [3]Gunathilleke (1994), [4]Pushpakumara (2000), [5]Perera and Perera (1997), [6]Wiersum (1977), [7]Soemarwoto et al. (1985), [8]Vien (2003), [9]Trinh et al. (2003), [10]Luu (2001)

Livestock are an integral part of some homegardens, and their selection is determined by sociocultural, environmental, financial, and religious concerns (Soemarwoto 1987). These mainly provide nutritional security but also a source of additional income. Waste is also used for manure to maintain soil fertility and sustain production. The livestock component has relatively less importance in Javanese and Kandyan homegardens (McConnell 2003) but plays an important role in VAC systems. VAC systems often also include aquaculture ponds.

Homegarden fiber is an important source of fuel wood and timber for rural households. Wiersum (1977) found that homegardens are important to fulfill energy demands of rural households. In Sri Lanka, Kandyan homegardens are considered the most important source of fiber in non-forest land (Gunathilleke 1994). Northern mountainous areas in Vietnam typically have a VAC system combined with forestry.

High homegarden species diversity suggests a strong potential gene pool for future breeding programs that can strengthen crops and improve agricultural productivity (Soemarwoto 1980; Karyono 1981; DoA 2007).

Homegardens are also an important source of production and in situ conservation of medicinal plants. Although the economic values of homegarden medicinal plants are not commonly exploited, they are widely used within households and communities for medicinal values (Rao and Rao 2006). In VAC gardens the diversity of medicinal plants is higher than vegetables, fruits, and other plants (Trinh et al. 2003). A key role of homegardens is to supply nutritional and food security to households by a steady supply of necessary vegetable proteins, carbohydrates, vitamins, and minerals, particularly during lean periods (Abdoellah 1985).

6.3.4.2 Regulating Services

Global and local climate regulation, erosion control, pest control, and pollination are some of the key regulating services provided by homegardens (Jose 2009; Mohri et al. 2013; Rao et al. 2007).

6.3.4.2.1 Climate

A basic characteristic of homegardens is a multilayered structure, which regulates microclimate by influencing air temperature, solar radiation flux, soil moisture, wind speed, and maintaining ambient temperature (Rao et al. 2007). Homegardens also contribute to global climate regulations by storing carbon and mitigating greenhouse gas emissions. According to James (2002), Indonesian homegardens store equivalent carbon to secondary forests in the same area. The UNFCCC's Clean Development Mechanism (CDM) can provide additional income for further enhancing or protecting homegarden carbon stocks (Mohri et al. 2013), especially in Sri Lanka (Szott and Kass 1993; Mattsson et al. 2009). Homegardens cover a third of Kandy region and provide a central source of carbon storage for the country (Pushpakumara et al. 2010). On the other hand, while shifting to homegardens has encouraged some tree planting in Vietnam, new VAC systems may have a net negative impact on climate regulation as they generally use more fossil fuels than the swidden cultivation or forestry they often replace because of increased livestock activities and rice cultivation (Leisz et al. 2007; Mohri et al. 2013).

6.3.4.2.2 Soil Erosion

Soil erosion is a critical issue for many farmers, especially in steep lands (McConnell 2003). Multilayered canopy structure and dense root architecture of homegardens can mitigate erosion risk (Torquebiau 1992). Homegarden plants and trees are rarely harvested completely, further minimizing erosion risk compared to more intensive agriculture (Gajaseni and Gajaseni 1999). In Sri Lanka, where landslides and soil erosion are a widespread danger, typical homegardens have a soil erosion rate comparable to native forests, a rate less than 1% of conventional annual cultivation systems (Wagachchi and Wiersum 1997; Pushpakumara et al. 2010).

6.3.4.2.3 Pest Regulation

Livestock is often used to control pests. For example, in Javanese homegardens peanuts are planted near the house to attract insects and make it easy for chickens to find and eat them (McConnell 2003). High homegarden biodiversity is likely to reduce the risk of pests and plant diseases compared to monoculture farming, but further scientific evidence is required to better assess homegarden pest regulation services (Mohri et al. 2013).

6.3.4.2.4 Pollination

Homegardens are likely to have an important role in pollination, natural hybridization, and seed dispersal (Mohri et al. 2013). Kandyan homegardens are home to many animals and insects which maintain these services (Pushpakumara et al. 2010; Mendis et al. 1985), but further research is needed on pollination services provided by Javanese homegarden and VAC systems (Mohri et al. 2013).

6.3.4.3 Cultural Services

Homegardens are also a major part of culture for rural communities. Many plants selected for cultivation reflect cultural preferences, such as ornamental and eating preferences, rather than productive purposes. Homegardens also play an important social role. In Java, homegardens are a social status symbol and can enhance social networks in communities. For example, traditional homegardens are generally bordered by shrubs or small trees that allow easy access for neighbors to fetch water, collect medicines, and pass through. In Indonesia, the traditional concept of free sharing of homegarden products among relatives and neighbors (*rukun tetangga*) fosters social equity and social fabric. In Vietnam, homegarden products are used for various ceremonies, especially fruits for Vietnamese New Year and competitions for the best cultivated homegarden products (Trinh et al. 2003; Mohri et al. 2013).

6.3.4.4 Supporting Services

Homegardens provide biomass production, nutrient cycling, soil formation, and habitat services that support other ecosystem services. In Java, homegarden litter production, decomposition, and biomass cycling can occur at higher rates than typical forests (Gajaseni et al. 1999). In Vietnam, homegardens return waste from the home, garden, pond, and livestock as fertilizer and biomass energy (Mohri et al. 2013). Further study is needed to better highlight the importance of homegarden systems in nutrient cycling and soil formation (Mohri et al. 2013).

6.3.4.5 Biodiversity

Homegardens provide habitat for a large number of flora and fauna, including many endangered species, helping conserve biodiversity (Soemarwoto and Conway 1992;

Pushpakumara et al. 2010; Mohri et al. 2013). They often provide refuge in areas where urban development or agricultural intensification is having negative impacts on overall biodiversity. In Kandy, homegardens often link agricultural and natural landscapes, reducing risks of population fragmentation and enabling vital gene flow and seed dispersal (Pushpakumara et al. 2010).

6.3.5 Drivers of Change in Homegarden Systems

The flexibility and diversity of homegardens make them flexible and adaptable to environmental and socioeconomic change (Peyre et al. 2006). However, some homegardens are responding to change with more commercial systems that have reduced diversity (Peyre et al. 2006; Wiersum 2006; Mohri et al. 2013). Wiersum (2006) identifies the main drivers of change in homegardens as socioeconomic changes, commercialization, population growth, changes in farming systems, scientific innovations in the healthcare sector, invasive alien plant species, inheritance, urbanization, climate change, overexploitation, and pollution. Market demand also drives more cash crop production and monoculture (Soemarwoto and Conway 1992; Kumar and Nair 2004; Abdoellah et al. 2006). Seed exchange among homegardens may be one of the major sources of invasive alien plant species threatening floristic diversity (Marambe et al. 2003; Kumar and Nair 2006). Population growth and urbanization fragments and reduces homegarden size, decreasing income and driving farmers to off-farm employment (Christanty et al. 1986; Mohri et al. 2013). In a Javanese village near Yogyakarta, fish ponds are one of the typical components of homegardens, but overexploitation and pollution have caused some to be abandoned or converted to other use such as livestock (cattle) production due to deterioration of water quality (Mohri et al. 2013). The price increase of feedstock was also a major factor (Mohri et al. 2013).

Climate change is also considered to significantly threaten homegarden systems (Pushpakumara et al. 2010). Local farmers in the study areas pointed out recent changes in rainfall pattern, temperature, sea level, and extreme events like floods and drought at local scale, but only a few scientific assessments of the climate change impacts on homegarden systems have been conducted (Mohri et al. 2013).

6.4 A Case Study: Strategies to Enhance Homegarden Systems in Kandy, Sri Lanka

A case study was conducted in Kandy, central Sri Lanka, to better understand the drivers of change and potential strategies to make homegarden systems and household livelihoods more resilient to negative drivers of change. This section will also consider how lessons from this case study could be applied in other contexts.

6.4.1 Land Management Changes and Their Drivers: Study Area and Method

In 2012 and 2013, a biodiversity stocktake (70 households) and follow-up survey (31) of homegarden households were undertaken in five villages in the mountainous Kandy District of Sri Lanka's Central Province (Fig. 6.1, Landreth and Saito 2014). The biodiversity stocktake measured biophysical features and biological diversity in different homegardens. The follow-up survey identified how households perceived their homegardens to have changed over the last 10 years and why. In-depth literature review and interviews with village and national government officials and international development organizations complemented the survey. These were used to identify how different government and market-driven interventions could help homegardens meaningfully contribute to contemporary sustainable development issues at local, national, and global scales. The surveys provided information on drivers of land management choices, perceived climate and ecosystem change, performance of current intervention strategies, homegarden productivity, market dependency, and how households value ecosystem services for their well-being (Landreth and Saito 2014).

6.4.2 How Are Kandyan Homegardens Changing?

Land management is the key characteristic of homegardens that determines whether the ecosystem will transform into secondary forest or be driven to more intensive agriculture, both of which have positive and negative consequences for ecosystem services (Landreth and Saito 2014). Homegarden changes in Kandy fell under three broad categories:

1. Fifty-five percent were shifting some or all of the homegarden toward commercial simplification of cultivated species, resulting in less diverse agroforests.
2. Thirty-six percent were shifting some or all the homegarden toward partial (29%) or total (7%) abandonment of homegarden management, resulting in secondary forest succession.
3. Nine percent were maintaining homegarden management with no significant change to labor, crop diversity, or other key features of the system.

6.4.2.1 Simplification

All households that shifted toward commercial simplification reported an increase in income over the last 10 years. This simplification was typically done by replacing fruit trees and diverting labor to spices (typically nutmeg in Kulugammana, pepper

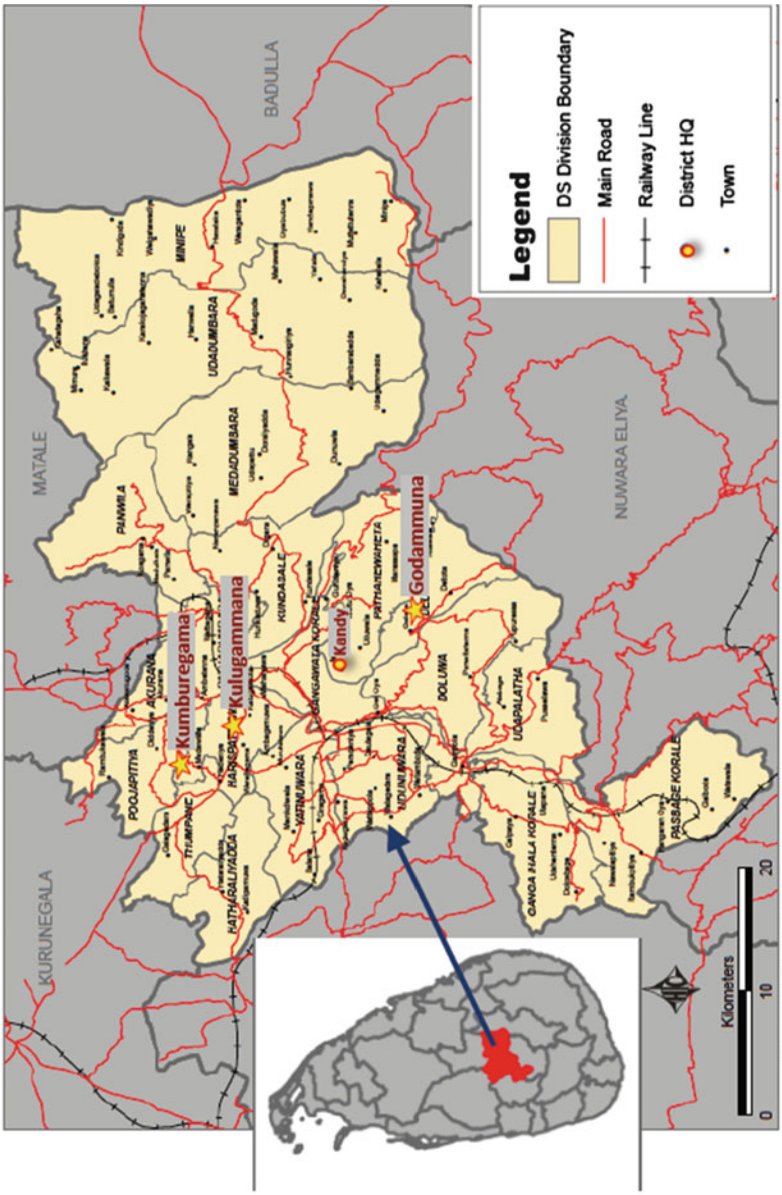

Fig. 6.1 Field survey sites in Kandy District, Central Province, Sri Lanka

in Godammuna, and to a lesser degree organically certified nutmeg and turmeric in Kumburegama). Some households also reported this simplification was driven by drought resilience as well as income. Simplification increased revenue and in some Kumburegama households drove an increase in homegarden cultivation area. However, it also had impacts to reduce food security, resilience to weather impacts, biodiversity, and all noneconomic ecosystem services identified by households as being important for long-term well-being. Households with diverse sources of income beyond the homegarden had lowest incidences of commercial simplification.

6.4.2.2 Abandonment

The benefits of abandoning homegarden cultivation included some improved environmental conditions and freed-up labor for other activities. Full or partial abandonment gave way to secondary forest succession, which still provides sources of fuel, timber, wild forage, and small amounts of market crops that can persist untended, such as pepper (Landreth and Saito 2014).

However, many of the homegarden species identified in the biodiversity stocktake relied on active human management and were outcompeted for soil space or sunlight when secondary forest took over. In Sri Lanka, secondary forests typically provide "depauperate" habitats for a less diverse number of dominating or invasive species (Pethiyagoda 2012), such as coffee, and increase habitat for destructive wild animals, amplifying existing damage problems from monkeys, boars, and porcupines.

6.4.2.3 Impacts of Simplification and Abandonment

The field survey found that, on average, homegardens provided around a quarter of household food staples. This ranged from a low of 12% in Kulugammana, where commercial simplification to increase spice production was highest; to 30% in Godammuna, where partial abandonment due to drought was highest; and to 47% in Kumburegama, where high market values for smaller amounts of organic crops had allowed households to maintain a balance of commercial and subsistence homegardening. Commercial simplification and abandonment reduce food production and increase dependence on markets for food. Households with greater dependence on markets were found to have limited diet diversity (usually less vegetables) and consume a greater proportion of processed foods, such as sweetened powdered milk or low-quality white bread that can have negative impacts on the spread of diabetes.

Simplification and abandonment also reduced the pool of local knowledge and genetic stocks, especially vegetables and other annuals, increasing reliance for some newer homegardeners on commercial seeds unsuited to local conditions and at higher risk of failure, especially during drought.

While secondary forests have lower average erosion rates than conventional agricultural landscapes, homegardens in Kandy typically include community-managed “lock-and-spill” drains that catch and redirect heavy water flows down steep hillsides. Abandoning homegardens also means abandoning components of this drainage system, which in recent heavy rains had resulted in heavier water flows damaging neighboring homegardens and silting lowland paddies.

6.4.3 Drivers of Change in Kandyan Homegarden Systems

Table 6.4 below shows main drivers of change identified in homegardens across the study area.

6.4.3.1 Increasing Wild Animal Damage

Wild animals had the greatest impact on maintaining the resilience of homegarden diversity and ecosystem services. All but one household reported wild animal incursions (primarily macaques, boars, and porcupines) had increased over the past 10 years to a level that was driving change in homegarden cultivation, and three households reported they had fully abandoned homegarden cultivation due to unmanageable animal incursions. Two households also responded by removing trees to limit macaque access (Landreth and Saito 2014).

Boar damage was most common, although macaques had a greater impact due to their greater mobility throughout the canopy. In the worst affected homegardens, recurring damage from boars and porcupines digging for tubers and worms or feeding on fruit tree bark had made cultivation of vegetables or new plants

Table 6.4 Drivers of change in Kandyan homegarden systems

Driver	Households (%)	Impact on land management choices
Increasing wild animal damage	84	Abandonment
		Simplification to spices and animal-resilient nonfood crops (e.g., nutmeg and pepper)
Water scarcity, including changing climate patterns	58	Abandonment
		Simplification to drought-resistant crops
Better market prices and access	55	Simplification to spices and organically certified commercial crops
Eating and/or ornamental preferences	71	Full or partial maintenance of multi-crop homegardens
National support programs	74	No impact
		Full or partial maintenance of multi-crop homegardens

Adapted from Landreth and Saito (2014)

untenable. Monkeys, primarily macaques, also damage established fruit trees. Nearly all households reporting increased macaque incursions were no longer able to harvest enough fruit from homegardens to meet household needs. Animal damage was the main reasons given for high average market dependency for coconuts (51% of households sourced entirely from market), fruits (83%), vegetables (91%, specifically due to boars and porcupines), fresh chili (81%), and coconut oil (92%).

By making it difficult to establish new plantings, wild animals made it difficult to maintain homegarden diversity, adapt to water scarcity and climate change, or recover from extreme weather events (typically increasingly heavy rains and drought). Kulugammana households reported that macaques had recently uprooted new plantings, tore unripe fruit from trees, and often stripped leaves from trees once fruit had been consumed. One Kumburegama household replanted around Rs. 200 of cabbages and chilies to replace those destroyed in recent extreme rains. Within a week boars and porcupines had destroyed the replacement plants.

Partial or full abandonment of homegarden management driven by wild animals, especially reduced undergrowth clearing and canopy pruning, has feedback impacts by increasing secondary forest succession that amplifies ideal boar and macaque habitat and feeding grounds.

6.4.3.2 Water Scarcity, Including Changing Climate Patterns

Fifty-eight percent of households attributed lower homegarden productivity to more unpredictable and extreme rainfall patterns. Traditional strategies for predicting and responding to weather, such as bird calls and flying ant mating habits, were reported as no longer reliable by households that used to apply this local knowledge (Landreth and Saito 2014). Some participants were able to specify when rainfall patterns noticeably changed (typically between the last 3–10 years).

Unpredictable rainfall reduced the security and productivity of crops for food and income, driving simplification to more drought- and rain-resilient species and driving some homegardeners to seek alternative incomes.

During the research period, an elongated drought broke in December 2012 with the heaviest rain reported in parts of the study area since 1953 (East Godammuna Grama Niladhari, pers. Comm., January 2013). For one household, the drought destroyed one season's harvest, and the following season was destroyed by the extreme rainfall. While extreme rainfall was considered by all households to be part of conventional homegarden management, abandonment of neighboring homegardens also reduced substantial benefits from lock-and-spill drainage techniques to manage erosion – only 3 of the 18 households employing these techniques reported erosion damage in the extreme rain.

6.4.3.3 Better Market Prices and Access

Surveyed households had an average monthly income of between Rs. 30,000 and Rs. 40,000, comparable to the national mean at the time of Rs. 36,451 (Central Bank of Sri Lanka Statistics Department 2012). On average, homegardens provided around 24% of household income, but this was across a wide range. Thirty-six percent reported homegardens as their primary source of income, and 23% reported no income from homegardens at all.

Fifty-five percent of homegardens had changed species composition in the last 10 years to generate more income. This primarily involved replacing ground cover annuals and fruit trees with valuable spices, especially nutmeg which has increased market value substantially in recent years.

Before an organic certification program arrived in the Kumburegama area in 2006, vegetables were the main source of income for the 18 households in the program. Nutmeg is now the leading source of income (President, Kumburegama Farmers' Association, pers. comm., Jan. 23, 2013). Sixty percent of surveyed Kumburegama homegardens reported minimal change to homegardens due to increased market value, increasing the profitability of existing crops rather than encouraging major changes to species composition. Turmeric cultivation had increased significantly in 60% of households but was not deemed to have significantly displaced previous crops in the area. Two households had cleared some timber and cloves to intensify nutmeg production, although similar and more intense changes in Kulugammana, where no homegardens are organically certified, indicate nutmeg intensification is a symptom of overall trends in increased market value rather than simply due to organic certification.

6.4.3.4 Eating and Ornamental Preferences

Cultural ecosystem services are still a major countervailing driver for households to maintain and increase multi-crop diversity in homegardens in the face of substantial pressure for change driven by animals, climate change, and market values. Seventy-one percent of households at least partially maintained diverse homegardens for eating preferences and 68% for ornamental preferences (Landreth and Saito 2014).

6.4.3.5 National Support Programs

At the time of the study, Sri Lanka's *Divi Neguma* policy was seeking to improve food security in one million "domestic economic units" (households) across Sri Lanka. Divi Neguma included the *Api Wawamu Rata Nagamu* program (National Campaign to Motivate Domestic Food Production, referred to here as Api Wawamu). Its core activities were targeted at maintaining the contribution of homegardens to sustainable livelihoods, Sri Lankan cultural values, and national economic development. The program provided education and information on better natural resource management, subsidies for seeds, and postharvest technology and coordinated farmer organizations to improve irrigation and market access.

Seventy-four percent of households reported voluntarily participation in *Api Wawamu* programs. However, only between 10% and 30% of households reported national interventions as successful in improving homegarden cultivation and productivity, depending on the initiative, suggesting these programs may have limited effectiveness in the Kandy region.

6.4.4 Strategies to Address Drivers and Enhance Homegarden Systems in Kandy

Homegarden systems offer a range of ecosystem services that have adapted over the centuries to provide ecosystem services still relevant in a contemporary development context. Households, governments, and markets are responding with strategies to address drivers and enhance the services these systems can provide to human well-being and the broader environment.

6.4.4.1 Wild Animal Strategies

Traditional strategies at the household scale to protect against wild animals often required people to be constantly at home to fend off animals, repair fences, or set up cages. This becomes more difficult as contemporary Sri Lankan rural livelihoods become more diverse (58% of surveyed households had another source of off-farm employment) and children are educated at schools rather than staying at home. The low required maintenance of homegardens is one of the reasons they can adapt to changing employment preferences, as homegardeners can take off-farm employment without upsetting land management too significantly. Solutions to wild animals may not be successfully taken up if people must consistently watch the homegarden.

Over 50% of surveyed households had instead responded by accepting cohabitation with increased numbers of wild animals. These households had replaced easily damaged crops with commercial spices or more timber, considered resilient to most wild animal damage and delivering greater income benefits. This strategy resulted in significant loss of agricultural and biological diversity, provisioning services, and cultural services.

Preventative strategies for dealing with wild animals were limited by Sri Lanka's *Flora and Fauna Protection Ordinance* (1937, s3.44) that states no animal shall be hunted, killed, or taken unless caught harming crops. However, illegally caught porcupine and boar meat is sold and consumed throughout Sri Lanka (FAO 2002), and boar meat has potential to be a significant sustainable livelihood opportunity to sell in urban markets (Samaraweera et al. 2011).

With proper targeting and training, hunting permission could be extended to licensed operators in the Kandy District while keeping with the spirit of the Flora and Fauna Protection Ordinance allowance of population control to prevent future crop damage, not just limited to capture and trapping of animals caught in the act. If monitored sustainably, the sale of boar meat could provide significant additional income for local communities while reducing the number of boar incursions on valuable and new crops (Samaraweera et al. 2011).

For endangered macaques, translocation to reinvigorated habitats in reforested former tea plantations or underutilized state forests far uphill from affected homegardens could be a more appropriate strategy. This has been trialed in the Kandy region at a small scale, but the success of this strategy has yet to be evaluated.

6.4.4.2 Water Scarcity and Climate Change Strategies

Households with access to reliable water sources or stable alternative incomes were less likely to consider climate change responses necessary, applying existing lock-and-spill drainage as the main response to mitigate risk of increasing or more frequent heavy rainfall damage. Traditional knowledge was applied in other households to change the mix of species to more drought-resilient species, including mango, nutmeg, pepper, vanilla, tamarind, brinjal, and jak. Four households were increasing timber and sandalwood to provide income security in anticipation of future climate stress on their regular commercial and food crops. However, climate impacts and homegarden changes made in response reduced diversity, increased the need for additional sources of income, and increased expenditure on market-sourced food (especially vegetables). Reduced diversity has also been found to reduce resilience to weather fluctuations (Marambe et al. 2012; Weerahewa et al. 2012).

An important village-scale response is to improve water infrastructure. Fifty-three percent of households reported they did not have year-round access to nearby water sources, restricting their capacity to diversify into more commercial or resilient species.

6.4.4.3 Market Strategies

Homegardens already use limited agrochemicals and labor and so are well suited to organic and fair-trade certification that can attract high premiums if produce can be delivered at scale and consistent quality. Other ecosystem services that homegardens provide of value to global organic and fair-trade markets include biological diversity, global climate regulation, protection of nature, agricultural biosafety, consumer health, and "fair-trade" working conditions (Landreth and Saito 2014).

While some organic and fair-trade certification bodies require biodiversity conservation plans, these may be of low sensitivity to local conditions. Some certified households reported increased simplification to take advantage of commercial crops. Certification standards could consider relaxing some requirements in place of better safeguards to avoid perverse outcomes of commercial homegarden success, such as to prevent reduced agrodiversity that may lead to greater reliance on expensive and unhealthy market-sourced food and reduced species important for pollination.

6.4.4.4 National Support Programs

Api Wawamu programs had a broad reach into surveyed households but could be a more effective driver of homegarden resilience. The promotion of container gardens with free seeds for kitchen use, usually in gunny sacks or coconut husks near the home, was taken up by around 30% of respondents. No households reported container garden damage due to wild animals, suggesting these smaller plantings could be useful fallbacks for small-scale food cultivation or to meet eating preferences in homegardens with heavy animal incursions.

Twenty-six percent of households reported that *Api Wawamu* instructors provided advice that improved productivity, including to introduce households to organic certification programs, suggesting education could be a significant driver for improved home gardening. Only one household that implemented instructor advice reported it was poor advice. However, 58% reported that they were not offered instructor advice, and 26% of all households indicated they would not trust national instructor advice if it was offered.

Around 52% of households did not bother with *Api Wawamu* distributed seeds and plantings. For many of these households, local knowledge was considered superior for local conditions compared to advice from instructors. Improving the quality and local sourcing of *Api Wawamu* distributed seeds and plantings could improve outcomes of this type of program in other situations. While around 60% of households that propagated *Api Wawamu* plants reported they were successful, they were mainly for small container gardens. Other households criticized the program for distributing commercial hybrids that could not be organically certified and thus worth less in export markets. Distributed seeds and plantings were also typically commercial varieties engineered for intensive production, not suited to household eating preferences and local conditions.

6.4.5 Lessons from Kandyan Homegardens

This research found that homegardens deliver a range of ecosystem services with substantial potential to adapt to and complement contemporary sustainable development priorities. However, rapid changes, particularly increased wildlife conflicts, market access, and climate change, are driving commercial simplification and abandonment with often unintended trade-offs. National and international interventions to maintain homegardens have typically focused on cost barriers (such as through subsidies) and developing natural resource management skills (such as through agricultural instructors). The ecosystem services-based analysis applied in this research can enhance these strategies by helping them identify and adapt to positive drivers, such as changing seed distribution programs to reflect local eating preferences, or build safeguards against negative drivers, such as including local biodiversity plans in organic certification guidelines or adjusting agricultural instruction to focus on responding to wildlife conflict.

6.4.6 Reestablishing Homegardens in Northern Sri Lanka

Lessons from the above studies on homegarden ecosystem services and the case study in Kandy could be applied in other places like the Northern Province of Sri Lanka, where people suffer from harsh environmental conditions and socially unstable situations. Since the 25-year civil war ended in 2009, the Northern Province in Sri Lanka has progressed from destruction to reconstruction through economic and infrastructure development, but still people in the region struggle to sustain their livelihoods. A number of field surveys were conducted in the area to evaluate the current agriculture practices and farmer livelihoods and propose some recommendations to improve livelihoods in Northern Sri Lanka. One hundred and two samples were collected from a household survey conducted in four divisions in Kilinochchi District, Pooneryn, Pachchilaipalli, Kandawali, and Karachchi. Northern Sri Lanka is heavily dependent on the agriculture sector. Poverty rates in the region are relatively high compared to other parts of the country, and people have limited access to the land and other natural resources. Many farmers depend on their limited land to have homegardens but during the war were separated from their land and have lost homegarden knowledge and management skills. As demonstrated in assessments from other regions discussed in this chapter, reestablishing homegardens has great potential to improve not only livelihoods but also the damaged natural environment around the region. As this research showed, the Kandy homegardens maintain high biological diversity and contribute significantly to livelihoods. Kandyan strategies could be incorporated into the development plans in the Northern Province to build homegarden knowledge and skills, integrated into agricultural development efforts such as training programs, water management efforts, and government subsidies for fertilizers.

6.5 Conclusion

This chapter shows the multitudinous benefits of homegardens and potential strategies to enhance the contribution of homegardens to livelihoods and resilience against environmental, climatic, and social changes. This found substantial scientific research has been conducted on homegarden systems, with some notable gaps in socioeconomic aspects of the systems (Kumar and Nair 2004; Mohri et al. 2013).

Homegardens provide many services for people in rural areas: an income source, a place for communication, a livelihood protection from environmental and economic shocks, and a means of conserving traditional culture, biodiversity, and agrodiversity. While this paper found similarities in components, spatial layout, temporal and spatial scales, diversity, and functions of homegarden in the study areas, characteristics and functions differ at regional and local scales. This diversity and multifunctionality of homegardens reflect their adaptability and how they can play an important role in providing *general resilience* against social, economic, climatic, and ecosystem changes. *General resilience* is a system or function that has the capacity to recover from different types of shocks and cope "with uncertainty in all ways" (Folke et al. 2010) which can be distinguished from *specific resilience*, that is more specialized on a specific event or disturbance (Carpenter et al. 2001; Folke et al. 2010; Mohri et al. 2013).

In the study areas, homegardens generally still exist in some form despite substantial impacts and change. One of the main challenges will be to integrate such traditional homegardens with rapid changes to modern technology and global economy to enhance the resilience of the system against new issues. The longevity and adaptability of Kandyan homegardens provide an example of how mixed-crop smallholder agriculture can be positioned positively in contemporary sustainable development for other communities vulnerable to or recovering from climate change and socioeconomic and political instability impacts.

References

Abdoellah OS (1985, December 2–9) Homegardens in Java and their future development. Paper presented in the 1004 international workshop on tropical homegardens. Held at the Institute of Ecology, Padjadjaran University, and Bandung, Indonesia

Abdoellah OS, Parikesit G, Gunawan B, Hadikusumah HY (2001) Homegardens in the Upper Citarum Watershed, West Java: a challenge for in situ conservation of plant genetic resources. Presented in international workshop: contribution of homegardens for in situ conservation of plant genetic resources in farming systems, July 17–19, 2001, Witzenhausen, Germany, pp 140–147

Abdoellah OS, Hadikusumah HY, Takeuchi K, Okubo S, Parikesit G (2006) Commercialization of homegardens in an Indonesian village: vegetation composition & functional changes. Agrofor Syst 68:1–13

An NTN (1997) A study on the home garden ecosystem in the Mekong River Delta and the Ho Chi Minh City. Working paper of South-South Co-operation programme on environmentally sound socio-economic development in the humid tropics, No. 7, UNESCO

Carpenter SR, Walker BH, Anderies JM, Abel N (2001) From metaphor to measurement: resilience of what to what? Ecosystems 4:765–781

Christanty L, Abdoellah OS, Marten G, Iskandar J (1986) Traditional agroforestry in West Java: the pekarangan (homegarden) and kebun-talun (perennial/annual rotation) cropping systems. In: Marten GG (ed) Traditional agriculture in Southeast Asia: a human ecology perspective. Westview Press, Boulder/London, pp 132–156

DoA (Department of Agriculture, Government of Sri Lanka) (2007) Country report on the state of plant and genetic resources in agriculture, Sri Lanka. AG: GCP/RAS/186/JPN Field Document No. 2007/08. Department of Agriculture, Sri Lanka, Colombo

Edwards P (2010) Rapidly changing aquaculture scene in the Red River Delta, Vietnam. Aquaculture Asia 15(4):3–10

FAO (2002) Forest resources of Sri Lanka 2000. FAO, Rome

Fernandes ECM, Nair PKR (1986) An evaluation of the structure and function of tropical homegardens. Agric Syst 21:279–310

Flora and Fauna Protection Ordinance (1937)

Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T, Rockstr € om J (2010) Resilience thinking: integrating resilience, adaptability and transformability. Ecol Soc 15(4):20

Gajaseni J, Gajaseni N (1999) Ecological rationalities of the traditional homegarden system in the Chao Phraya Basin, Thailand. Agrofor Syst 46:3–23

General Statistics Office of Vietnam (2013) Area, population and population density in 2011 by province. http://www.gso.gov.vn/default_en.aspx?tabid=467&ItemID=12941. Accessed 1 July 2017

Gunathilleke HM (1994) An assessment of the role of non-forest lands in future wood supply of Sri Lanka. In: Gunasena HPM (ed) Proceedings of the fifth regional workshop on multipurpose trees: MPTS for natural resource management, Kandy, Sri Lanka, April 1–3, 1994, pp 136–152

Gunatilleke N, Gunatilleke S, Abeygunawardena P (1993) Interdisciplinary research towards the management of non-timber forest resources in lowland rainforests in Sri Lanka. Econ Bot 47 (3):282–290

Hoogerbrugge I, Fresco LO (1993) [Remark 4] Homegarden systems: agricultural characteristics and challenges, Gatekeeper series no. SA39. International Institute for Environment and Development, London

Jacob VJ, Alles WS (1987) Kandyan gardens of Sri Lanka. Agrofor Syst 5:123–137

James MR, Matt D, Kurniatun H, Pratiknyo P (2002) Carbon stocks in Indonesian homegarden systems: can smallholder systems be targeted for increased carbon storage. Am J Altern Agr 17 (2):138–148

Jose S (2009) Agroforestry for ecosystem services and environmental benefits: an overview. Agrofor Syst 76:1–10

Karyono (1981) Structure of homegarden in the rural area of Citarum watershed, West Java. Ph.D. thesis, Padjadjaran University, Bandung, Indonesia

Kehlenbeck K, Arifin HS, Maass BL (2007) Plant diversity in homegardens in a socio-economic and agro-ecological context. In: Tscharntke T, Leuschner C, Zeller M, Guhardja E, Bidin A (eds) Stability of tropical rainforest margins: linking ecological, economic and social constraints, environmental science. Springer, Berlin, pp 297–319

Kumar BM, Nair PKR (2004) The enigma of tropical homegardens. Agrofor Syst 61:135–152

Kumar BM, Nair PKR (eds) (2006) Tropical homegardens: a time-tested example of sustainable agroforestry. Springer, Dordrecht

Landreth N, Saito O (2014) An ecosystem services approach to sustainable livelihoods in the homegardens of Kandy, Sri Lanka. Aust Geogr 45(3):355–373

Leisz SJ, Rasmussen K, Olesen JE, Vien TD, Elberling B, Christiansen L (2007) The impacts of local farming system development trajectories on greenhouse gas emissions in the northern mountains of Vietnam. Reg Environ Chang 7:187–208

Luu LT (2001) The VAC system in Northern Vietnam, Integrated Agriculture-Aquaculture. FAO, Rome

Marambe B, Amarasinghe L, Gamage G (2003) Sri Lanka. In: Pallewatta N, Reaser JK, Gutierrez AT (eds) Invasive Alien species in South-Southeast Asia: national reports and directory of resources. Global Invasive Species Programme, Cape Town, pp 91–103

Marambe B, Weerahewa J, Pushpakumura G, Silva P, Punyawardena R, Premalal S, Miah G, Roy J (2012) Vulnerability of home garden systems to climate change and its impacts on food security in South Asia. http://www.apn-gcr.org/resources/files/original/3ddf57b875774091a38f95bdfee0b6c9.pdf. Accessed 9 Oct 2017

Mattsson E, Ostwald M, Nissanka SP, Holmer B, Palm M (2009) Recovery and protection of coastal ecosystems after tsunami event and potential for participatory forestry CDM – examples from Sri Lanka. Ocean Coast Manage 52:1–9

McConnell DJ (1992) The forest-garden farms of Kandy, Sri Lanka. FAO, Rome

McConnell DJ (2003) Nature. In: The forest farms of Kandy and other gardens of complete design. Ashgate Publishing, Farnham, pp 1–56

Mendis MN, Gunatilleke CVS, Gunatilleke IAUN (1985) Evaluation of bee pasturage potential in Kandyan home gardens. In: Proceedings of the 41st annual sessions of the SLAAS, pp 65–66. http://www.academia.edu/28923584/Assessment_of_ecosystem_services_in_homegarden_systems_in_Indonesia_Sri_Lanka_and_Vietnam

Millennium Ecosystem Assessment (MA) (2003) Ecosystem and human well-being–a framework for assessment. Island Press, Washington, DC

Millennium Ecosystem Assessment (MA) (2005) Ecosystem and human well-being–summary for decision makers. Island Press, Washington, DC

Mohri H, Lahoti S, Saito O, Mahalingam A, Gunatilleke N, Irham et al (2013) Assessment of ecosystem services in homegarden systems in Indonesia, Sri Lanka, and Vietnam. Ecosyst Serv 5(4):124–136. https://doi.org/10.1016/j.ecoser.2013.07.006

Nguyen VM (1997) Chapter 6: VAC and permaculture in Viet Nam. In: Proceedings of sixth international permaculture conference and convergence, September 27 to October 7, 1996 in Perth and Bridgetown, Australia

Ochse JJ, Terra GJA (1937) The economic aspect of the “Koetawinangun report”. Landbouweekblad 13:54. (in Dutch)

Perera ANF, Perera ERK (1997) Kandyan forest gardens: an agroforestry system with high potential for livestock production. Third annual forestry symposium, Department of Forestry and Environmental Science, University of Sri Jayawardenapura, Sri Lanka (abstract)

Pethiyagoda R (2012) Biodiversity conservation in Sri Lanka’s novel ecosystems. Ceylon J Sci (Biol Sci) 41(1):1–10

Peyre A, Guidal A, Wiersum KF, Bongers F (2006) Dynamics of homegarden structure and function in Kerala, India. Agrofor Syst 66:101–115

Phong LT, Udo HMJ, van Mensvoot MEF, Bosma RH, Nhan DK, Tri LQ, van der Zjipp AJ (2003) Integrated agriculture-aquaculture systems in the Mekong Delta, Vietnam: an analysis of recent trends. Asian J Agr Dev 4(2):52–66

Phong LT, Udo HMJ, van Mensvoort MEF, van Dam AA, Tri LQ, van der Zijpp AJ (2006) Quantitative agro-ecological indicators and productive performance of integrated agriculture aquaculture systems in the Mekong Delta. In: van der Zijpp AJ, Verreth JAJ, Tri LQ, van Mensvoort MEF, Bosma RH, Beveridge MCM (eds) Fishponds in farming system. Wageningen Academic Publishers, Wageningen, pp 135–146

Phong LT, van Dam AA, Udo HMJ, van Mensvoort MEF, Tri LQ, Steenstra FA, van der Zjipp AJ (2010) An agro-ecological evaluation of aquaculture integration into farming systems of the Mekong Delta. Agric Ecosyst Environ 138:238–241

Puri S, Nair P (2004) Agroforestry research for development in India: 25 years of experiences of a national program. Agrofor Syst 61:437–452
Pushpakumara DKNG (2000) Kandyan homegardens: promising land management system for food security, biodiversity and environmental conservation. In: Gawande SP, Bali JS, Das DC, Sarker TK, Das DK, Narayanaswamy G (eds) Advances in land resources management for 21st century. Proceedings of the international conference on land resources management for food, employment, and environmental security held from November 9–13, 2000 at New Delhi, India. Soil conservation Society of India, pp. 433–445
Pushpakumara DKNG, Wijesekara A, Hunter DG (2010) Kandyan homegardens: a promising land management system in Sri Lanka. Sustainable use of biological diversity in Socio-ecological production landscapes. Background to the Satoyama initiative for the benefit of biodiversity and human well-being. CBD Technical Series No. 52, Secretariat of the Convention on Biological Diversity, Montreal, pp 102–108
Rao MP, Rao R (2006) Medicinal plants in tropical Homegardens. In: Kumar BM, Nair PKR (eds) Tropical Homegardens: a time-tested example of sustainable agroforestry. Springer, Dordrecht, pp 205–232
Rao KPC, Verchot LV, Laarman J (2007) Adaptation to climate change through sustainable management & development of agroforestry systems. SATe J 4:1
Samaraweera M, Himali SMC, Zeng SC, Jianlin H, Silva P (2011) Development of molecular tools to differentiate Sri Lankan wild boar (Sus scrofa affinis) meat from exotic and village pig (Sus scrofa domestica) meat. Trop Agric Res 23(1):11–20
Soemarwoto O (1980) Interrelations among population, resources, environment and development in the ESCAP region with special reference to Indonesia. Ecology and development publication No. 7, Institute of Ecology, Padjadjaran University, Bandung, Indonesia
Soemarwoto O (1987) Homegardens: a traditional agroforestry system with a promising future. In: Steppler HA, Nair PKR (eds) Agroforestry: a decade of development. ICRAF, Nairobi, pp 157–170
Soemarwoto O, Christanty L (1985) Homegarden in the tropics. In: Proceedings of the first international workshop on tropical Homegarden, Bandung, Indonesia, December 2–9, Institute of Ecology, Padjadjaran University, Bandung, and United Nations University, Tokyo
Soemarwoto O, Conway GR (1992) The Javanese homegarden. J Farm Syst Res Ext 2(3):95–118
Szott LT, Kass D (1993) Fertilizers in agroforestry systems. Agrofor Syst 23:157–176
Takeuchi K (2010) Rebuilding the relationship between people and nature: the Satoyama initiative. Ecol Res 25:891–897
Terra GJA (1954) Mixed garden horticulture in Java. Malays J Trop Geo 1:33–43
Torquebiau E (1992) Are tropical agroforestry homegardens sustainable? Agric Ecosyst Environ 41:189–207
Trinh LN, Watson JW, Hue NN, De NN, Minh NV, Chu P, Sthapit BR, Ezyaquirre PB (2003) Agrodiversity conservation and development in Vietnamese homegardens. Agric Ecosyst Environ 97:317–344
Ueda H (1996) A study on the villages and dwellings of ethnic minorities in Vietnam Part3: report on the VAC-system. Res Rep Architect Inst Japan Kinki Branch 36:701–704
Vien TD (2003) Culture, environment, and farming systems in Vietnam's Northern Mountain region, Southeast Asia. Studies 41(2):180–205
Wagachchi H, Wiersum KF (1997) Water management in agroforestry systems: integrated buffalo ponds and forest gardens in the Badulla District, Sri Lanka. Agrofor Syst 35:291–302
Weerahewa J, Pushpakumura G, Silva P, Daulagala C, Punyawardena R, Premalal S, Miah G, Roy J, Jana S, Marambe B (2012) Are homegarden ecosystems resilient to climate change? An analysis of the adaptation strategies of homegardeners in Sri Lanka. APN Sci Bull 2:22–27
Wiersum KF (1977) Fuel wood in Indonesia, future prospects for a traditional energy source. Institute of Ecology, Padjadjaran University, Bandung, Indonesia. Mimeograph

Wiersum KF (1980) Possibilities for use and development of indigeneous agro- forestry systems for sustained land use on Java. In: Furtado JI (ed) Tropical ecology and development. Proceedings of the 5th international symposium tropical ecology, Kuala Lumpur, p 515–521
Wiersum KF (1982) Tree gardening and taungya on Java: examples of agroforestry techniques in the humid tropics. Agrofor Syst 1:53–70
Wiersum KF (2006) Chapter 2: Diversity and change in homegarden cultivation in Indonesia. In: Kumar BM, PKR N (eds) Tropical homegardens: a time-tested example of sustainable agroforestry. Springer Science, Dordrecht, pp 13–24
World Bank (2011) World development indicators 2011. World Bank, Washington, DC
Zhu T (2006) Assessment of small-scale biogas systems and their widespread dissemination in can Tho City, Vietnam, ISP Collection, Paper 303

Chapter 7
Integrated Water Resource Analysis of the Deduru Oya Left Bank Considering Traditional and Modern Systems

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Abstract The Deduru Oya reservoir which was commissioned in 2014 is primarily planned to improve the livelihood of farmers in parts of the North Western Province of Sri Lanka by increasing the productivity of its land and water resources by regulating and diverting water to irrigation systems through two main canals in both riverbanks. This irrigation project is an example of integration of modern irrigation systems and traditional irrigation systems to improve cropping intensity and resilience. In this study, a model for water management in the left bank (LB) canal development area of the Deduru Oya irrigation project is developed. Hydrologic Modeling System (HEC-HMS) of Hydrological Engineering Center, US Army Corps Engineers is used for runoff estimation, and CROPWAT model of FAO is used for the estimation of crop water requirements. Water available for paddy cultivation in the area from each of the traditional irrigation systems is estimated, and the additional requirement of water from the Deduru Oya reservoir through the LB canal to satisfy the irrigation demand in the area is estimated.

Simulation carried out for the past 10 years reveals that the Deduru Oya reservoir project which functions incorporating the existing traditional irrigation systems would supply the irrigation water requirement for paddy cultivation in the LB canal irrigation area without failure.

Keywords Irrigation water requirement · Deduru Oya project · Hydrological modeling · WEAP

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K. Takeuchi et al. (eds.), *Resilient Asia*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56597-0_7

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7.1 Introduction

Deduru Oya basin located between northern latitude 7° 19′ 00″ to 7° 52′ 00″ and eastern longitude 79° 47′ 0″ to 80° 35′ 0″ has an area of 2620 km^2 with elevation ranging from 0 m to 1280 m MSL. It is the sixth largest river basin in Sri Lanka extending from Chilaw in the west coast to the central hills as shown in Fig. 7.1. The basin boundaries are Mee Oya basin to the north, central hills to the east, Maha Oya basin to the south, and coast to the west. The basin could be categorized into three regions according to geographical features, viz., coastal and alluvial region in the western end of the basin, mountainous region in the eastern boundary of the basin, and moderately sloping region in the middle of the basin.

The rainfall in the basin has a significant temporal and spatial variation. Annual rainfall ranges from 2600 mm in the upper basin to 1100 mm in the lower basin. The average annual rainfall in the basin is about 1600 mm, ranging from 50 mm in a dry month to 280 mm in a wet month (Jinapala et al. 2003). From the annual rainfall, about 50% is received during intermonsoon months (March, April, October, and

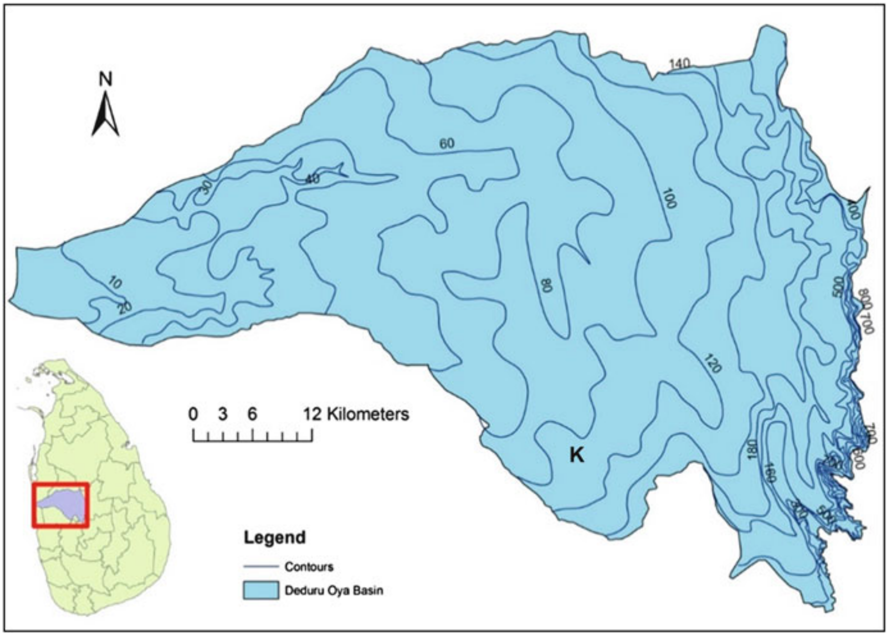

Fig. 7.1 Topography of the Deduru Oya basin

November), about 35% during southwest monsoon months (May to September), while the remaining 15% during northeast monsoon months (December to February). Representative rainfall in the basin is depicted by the records of the rain gauge at Kurunegala (Fig. 7.2). The average daily mean temperature varies between 28 °C and 32 °C.

Upper catchment of the river is nourished by water springs around Galagedara, in Kandy District, which receives about 2000–2250 mm of annual rainfall. The upper reaches of the main river have a high gradient, where the most upstream 16 km segment of the river has elevation ranging 200 m–1000 m. The Deduru Oya releases about 1600 million m^3 of water to the sea annually without being much used in the basin (National Atlas 2007). Deduru Oya carries flash floods during rainy season and very low flows during the dry season owing to the significant temporal variation of its basin rainfall. The single reservoir intercepting the Deduru Oya is the recently constructed reservoir in 2014 though there are several weirs across it to divert water for irrigation schemes.

7.2 Irrigation Systems in Deduru Oya Basin

Paddy cultivation is done under the tropical climate condition in Sri Lanka in two seasons per year: wet (*Maha*) season from October to March and dry (*Yala*) season from April to September. Deduru Oya basin is one of the major paddy cultivation basins in the country. A prominent feature in the Deduru Oya basin is that it

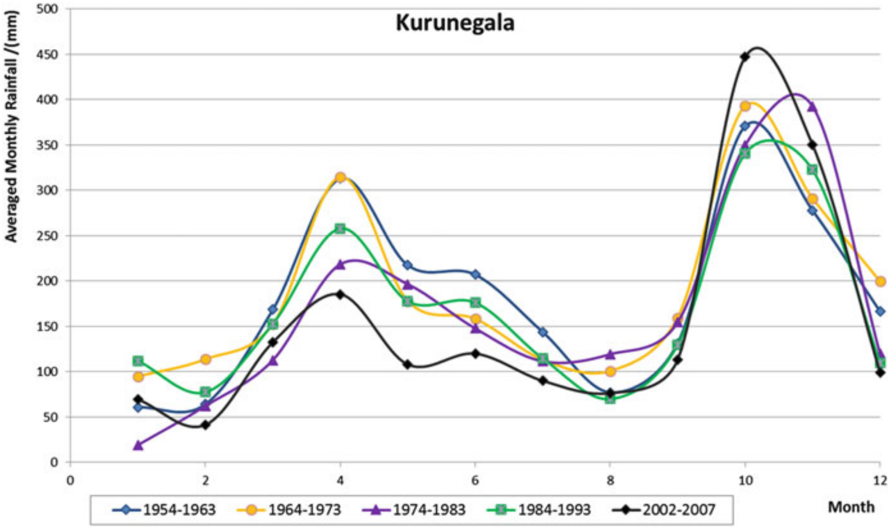

Fig. 7.2 Mean annual rainfall at Kurunegala gauging station, gauge location is shown as “K” in Fig. 7.1

contains approximately 3000 small reservoirs (called tanks) and cascade irrigation systems (Fig. 7.3). These irrigation systems are operated from ancient times, and tank construction in the basin is dated back to the periods of King Mahasen in 270 A.D. and King Parakramabahu in 1153–1186 A.D. (Parker 1889; Mahāvaṃsa 1912, Cūlavaṃsa 1929; Brohier 1935; Attygala 1948; Nicholas 1954). These systems are used to irrigate approximately 50,000 hectares of paddy lands in the basin which amounts to about 18% of the basin area. The surface water storage capacity of about 3000 small reservoirs scattered all over the Deduru Oya basin is about 400 million m^3 (Weerakoon et al. 2001). Despite this large number of reservoirs, the basin still suffers considerable scarcity of water at present. Changes of rainfall pattern with long drought seasons are the main reasons for this water scarciy. Cultivation of the total area under these irrigation schemes is possible only during *Maha* season. In *Yala*, lands under 60 percent of small reservoirs are not cultivated due to water scarcity (Somaratne et al. 2003). The Deduru Oya reservoir project which was recently commissioned in 2014 is expected to increase the cropping intensity of paddy cultivation in the Deduru Oya basin.

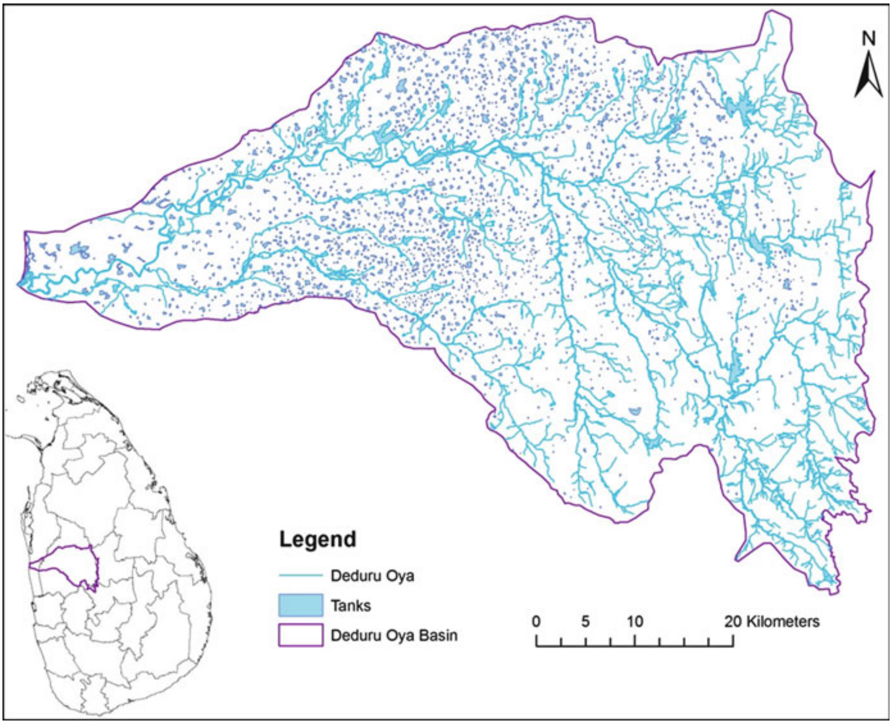

Fig. 7.3 Irrigation reservoirs and stream network in the Deduru Oya basin (Source: Survey Department)

7.3 Deduru Oya Reservoir Project

Deduru Oya reservoir project (Fig. 7.4) is a multipurpose water resource development project implemented by the Irrigation Department of Sri Lanka primarily to improve the livelihood of farmers in part of the North Western Province by increasing the productivity of land through irrigated agriculture. Block diagram of Deduru Oya reservoir project is shown in Fig. 7.5. The project includes construction of a dam across Deduru Oya at Thummodara which is 66.7 km along the Deduru Oya from the sea mouth to impound streamflow in a reservoir with a capacity of 75 million m^3, construction of two diversion canals at the left bank (LB canal) and right bank (RB canal) to provide irrigation for 11,415 ha of cultivated land, and installation of a 1.5 MW hydropower plant at the downstream of the dam. Other purposes of the project include enhancement of reliable sources for domestic and industrial water supply schemes, control downstream floods, and regulation of the flow to enhance existing diversion at 300 m downstream to Ridi Bendi Ela irrigation scheme.

The unique feature of the Deduru Oya reservoir is the design of LB canal where this contour canal supplements water to a large number of traditional tanks and

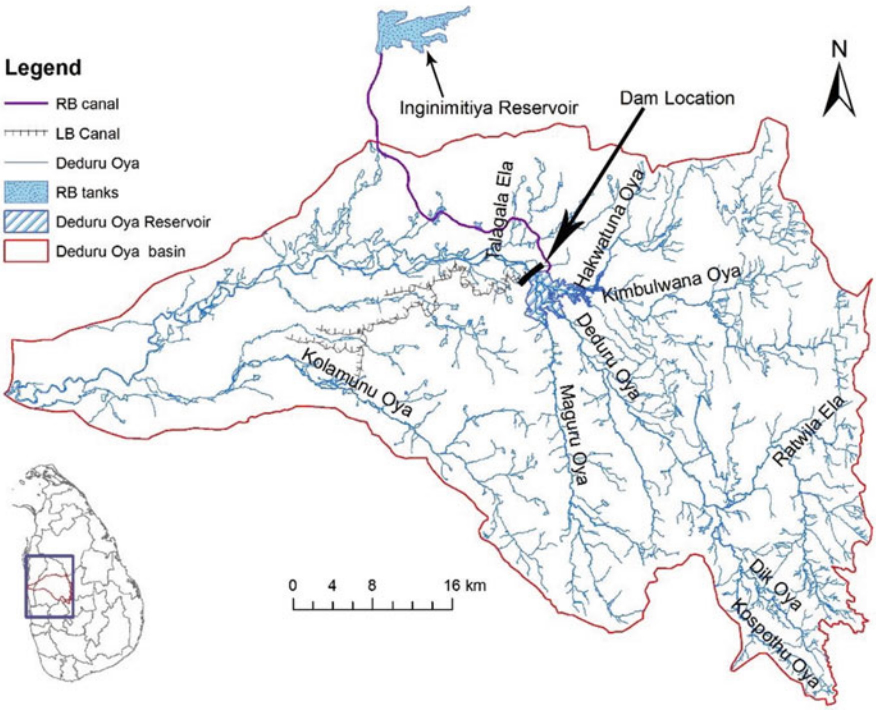

Fig. 7.4 Deduru Oya reservoir project

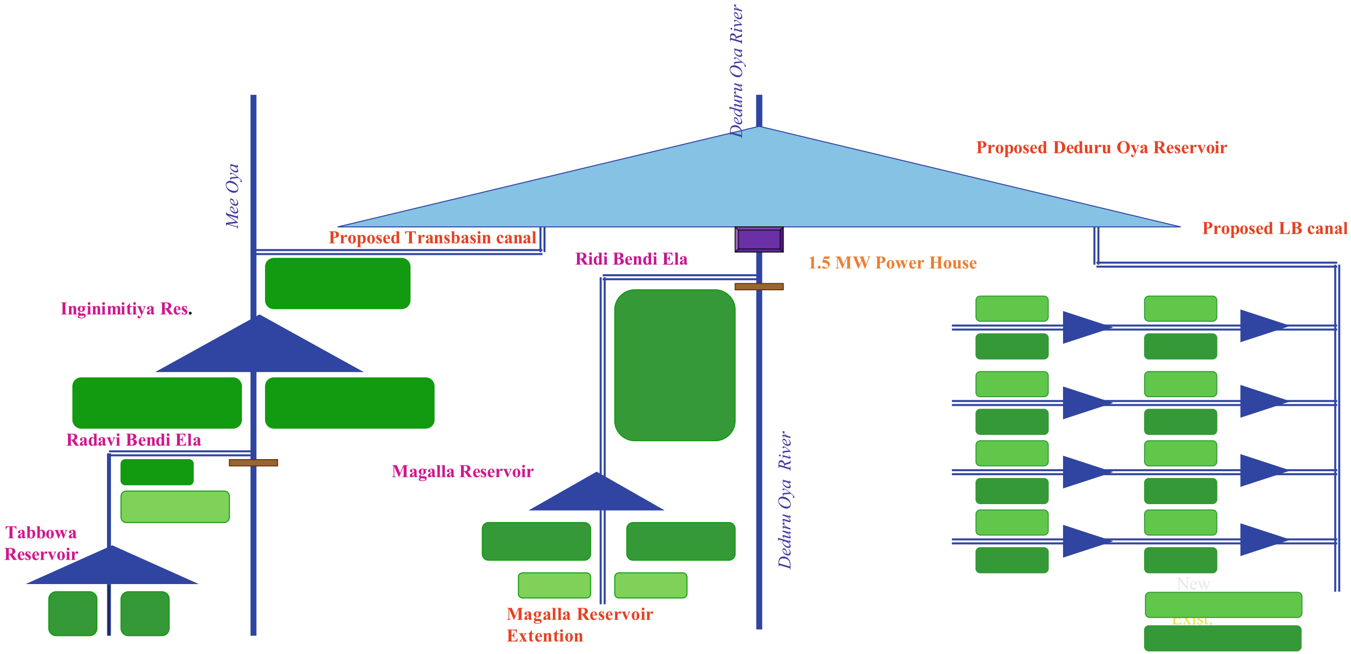

Fig. 7.5 Block diagram of Deduru Oya project

cascade systems to form a combination of traditional tanks and modern reservoir irrigation system.

RB canal is a transbasin canal to supply water to Iginimitiya reservoir which is located in the adjacent Mee Oya basin. It is proposed to develop 1000 ha along the transbasin canal and 5415 ha in the Mee Oya basin. Furthermore, 3000 ha in Ridi Bendi Ela scheme will be benefited by regulated water supply from the Deduru Oya reservoir (Table 7.1).

Release from the reservoir to the downstream of Deduru Oya is 7 m^3/s of which 5.65 m^3/s is for the diversion to Ridi Bendi Ela at 300 m downstream from the dam and the balance is for environmental flow at the downstream of the diversion (Pre-feasibility Report 2001).

7.4 Deduru Oya LB Canal Irrigation System

The Deduru Oya LB canal is 44.1 km long, and it supplies water to 136 existing storage-based ancient irrigation systems of the Deduru Oya (Fig. 7.6). The canal has a conveyance capacity of 7.1 m^3/s at the origin, and it forms 17 level crossings with small tanks along its length. It also supplies water to four branch canals (Fig. 7.6). Control outlets (CPO) provided in the branch canals release water to distribution canals and tanks (Table 7.2).

7.4.1 LB Canal Irrigation System: Combined System of Traditional Tank-Based and Modern Reservoir-Based Irrigation Systems

Irrigation systems consisting of modern and traditional systems are expected to improve overall resilience of the system and improve livelihoods of farmers through the increases in productivity (Herath et al. 2013). With the extreme weather events experienced in recent times attributed to climate change, more attention is given today on the sustainability and resilience of ancient irrigation systems based on distributed small storages. In order to improve sustainability and resilience of modern irrigated agricultural systems, it is imperative that resilient features of ancient irrigation systems are incorporated to modern irrigation systems. These combined system of traditional tanks and modern reservoir systems with the features of modern and ancient systems are expected to improve livelihood of farmers through sustainable and increased productivity. The Deduru Oya irrigation project in North Western Province of Sri Lanka is one such combined system of traditional tanks and modern reservoir irrigation project developed incorporating features of modern and ancient irrigation systems.

Table 7.1 Summary of new and existing irrigation areas

Canal	Existing area (ha)	Proposed new area (ha)
LB canal	2400	600
RB canal	4715	700
Ridi Bendi Ela	2400	600
Total	9515	1900

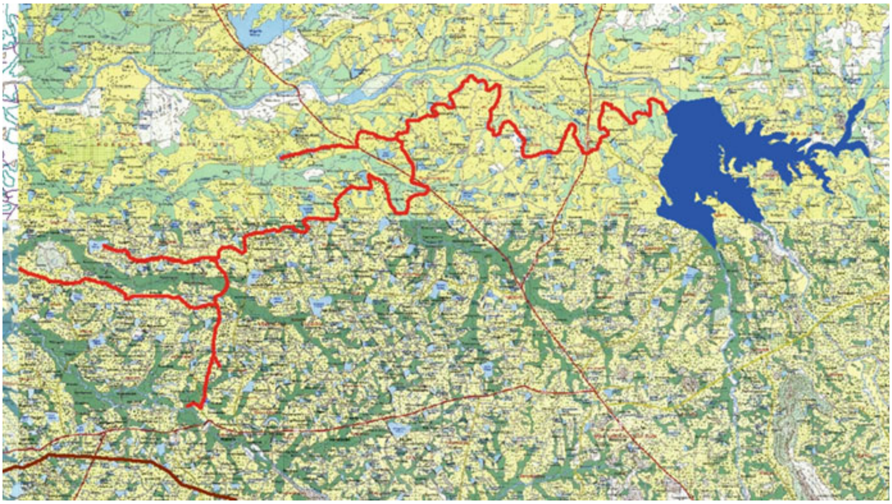

Fig. 7.6 Deduru Oya reservoir and LB canal

Table 7.2 Number of tanks receiving water from the main canal and branch canals

Canal name	Number of tanks	Capacity of the canal (m^3/s)
Main canal	77	7.08
Branch canal 1	15	4.25
Branch canal 2	16	2.83
Branch canal 3	27	1.42
Branch canal 4	1	1.42

The LB canal irrigation system is shown in Figs. 7.7 and 7.8. Each tank has its own catchment area to receive and store water derived from seasonal rains in order to irrigate the command area under the tank. With the operation of the LB canal, these tanks will also receive water from the Deduru Oya reservoir to supplement the irrigation demands from tanks to increase the cropping intensity of existing cultivations and also to increase the cultivation area under each tank.

While there have been a number of hydrological modeling studies on irrigation tanks and small cascade systems, a systematic study of the irrigation potential of

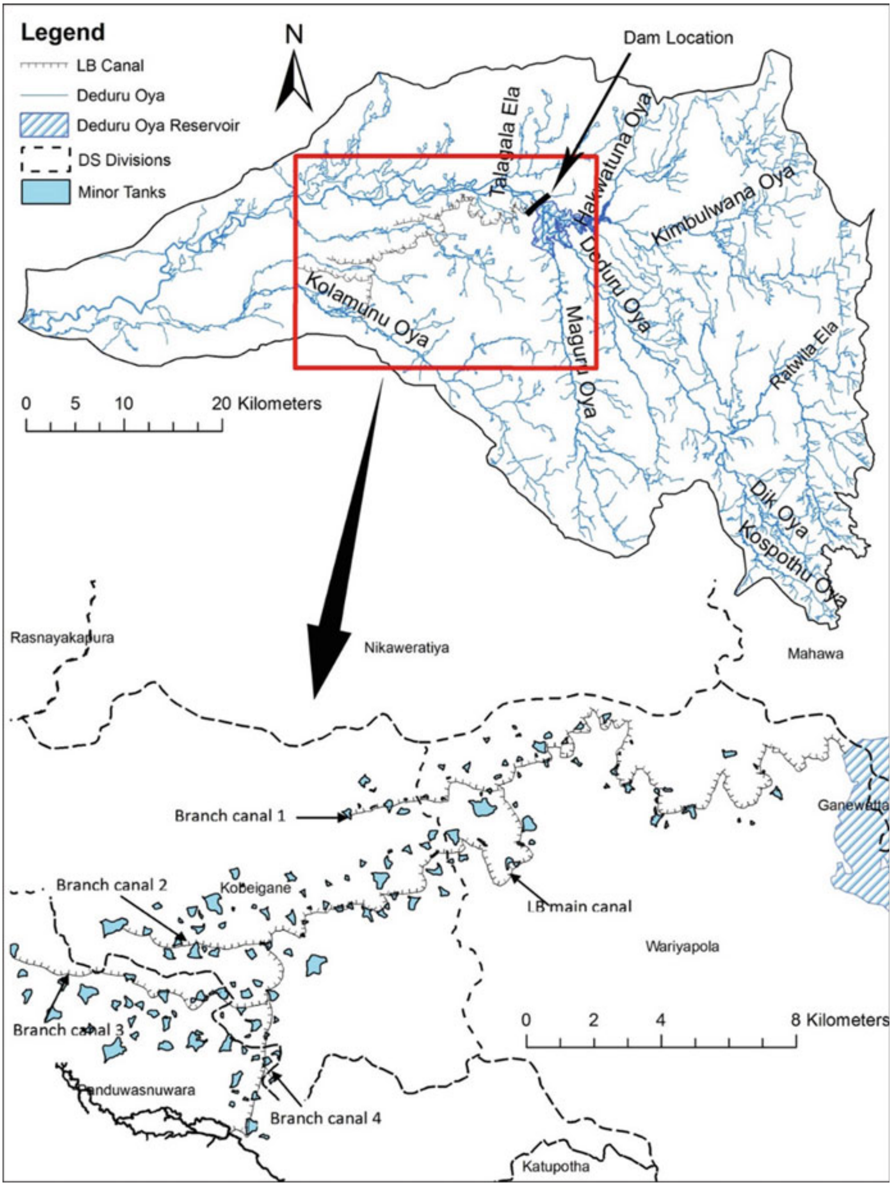

Fig. 7.7 Deduru Oya reservoir and LB canal

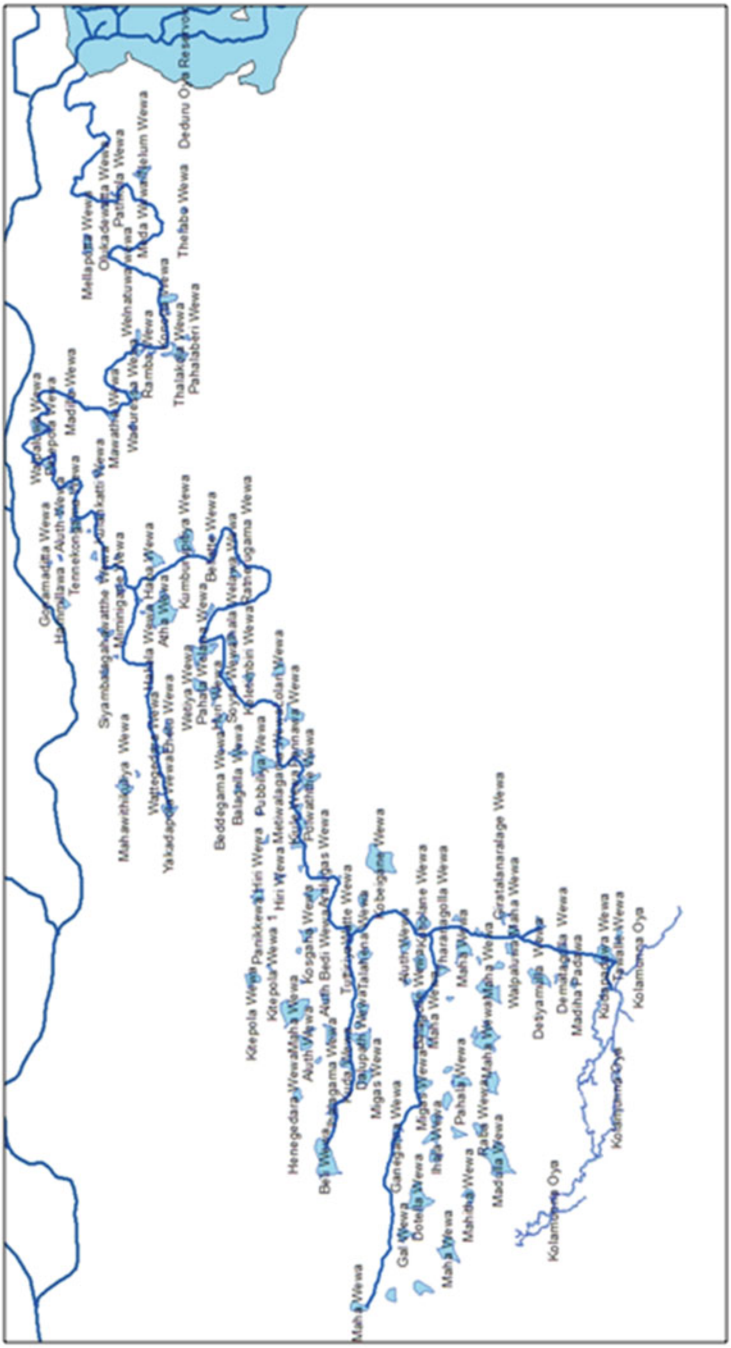

Fig. 7.8 Distribution of ancient tanks in the LB canal

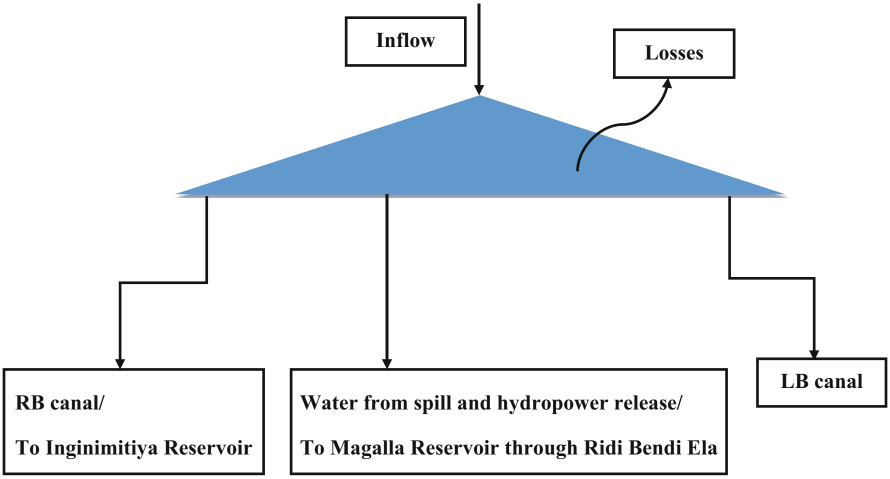

Fig. 7.9 Water accounting in the reservoir

ancient irrigation systems has not been done before. In this study, the availability of water resources for the LB development area in the traditional system and in the combined system after the project is analyzed. Major components of water accounting in the reservoir are shown in Fig. 7.9.

7.4.2 Estimation of Water Availability from the Traditional System for Irrigation in the LB Development Area

Inflows to the irrigation reservoirs in LB development area from their own catchments are not readily available, and therefore, a rainfall-runoff model was developed to estimate the direct inflows to the reservoirs from their own catchments. Rainfall-runoff model developed to Tittawella reservoir is used to set up and calibrate the inflows to ancient tanks in the LB development area. Tittawella reservoir is located about 10 km away from LB canal development area in the same agroclimatic region, and its catchment is hydrologically similar to the reservoir catchments in Deduru LB canal development area. Daily observed rainfall, runoff, and evaporation data of Tittawella catchment are available for the period of May 1995–March 1997 (Dept. of Irrigation 1998). The catchment area of Tittawella reservoir is 2.95 km^2 and the reservoir has a capacity of 0.31 million m^3. Major soil group is reddish-brown earth and soil depth is more than 120 cm. Longest water course is 1800 m long and catchment slope is 0.82%. The land use pattern in the basin is identified as homesteads 55%, paddy 25%, coconut 7.5%, and forest cover.

Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) version 3.0.1 developed by US Army Corps of Engineers in the USA was used as the rainfall-runoff model to estimate inflows of the tanks (Scharffenberg and Fleming 2006). The HEC-HMS supports both lumped parameter-based modeling and distributed parameter-based modeling and has been tested for tropical catchments (Agrawal et al. 2005). HEC-HMS has been successfully applied to many basins to assess water resources including river basins in Sri Lanka (De Silva et al. 2014, Halwatura and Najim 2013).

7.4.2.1 HEC-HMS Application to Tittawella Reservoir

HEC-HMS model was calibrated and validated for Tittawella reservoir using the observed daily rainfall and catchment runoff from selected storm events during October–November 1995, October 1996, and May 1995, and also using observed data of the continuous periods of September–November 1995, September–November 1996, September 1995–August 1996, and May 1995–March 1997 as shown in Figs. 7.10, 7.11, 7.12, 7.13, 7.14, 7.15, and 7.16, respectively. Figures 7.13, 7.14, 7.15, and 7.16 depict graphical comparisons of the calibration and validation results, respectively, for continuous simulation. The study used the computed skill metrics of simulated streamflow against observation as a criterion to calibrate model parameters. Table 7.3 shows that the skill of simulations of calibrated model normalized objective function (*NOF*), Nash-Sutcliffe efficiency $\left(R_{NS}^2\right)$, and percentage bias (δ_b) agrees reasonably well against observed discharges during both calibration and validation periods in event-based and continuous simulation.

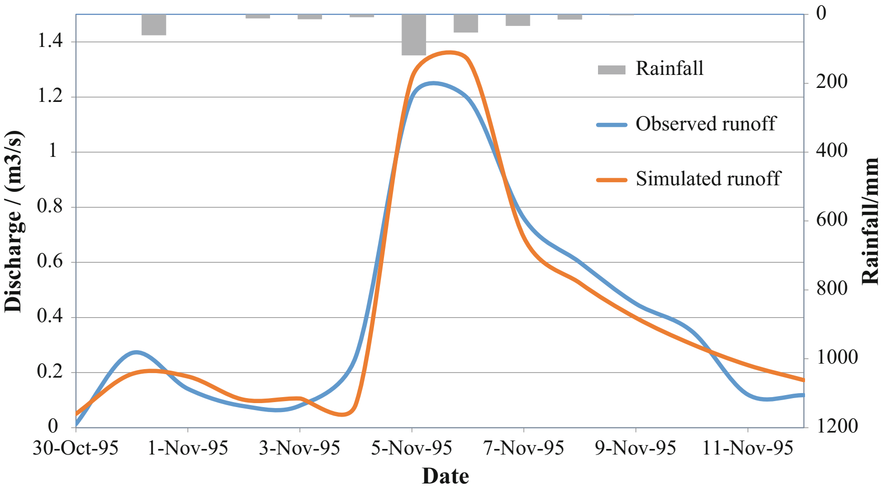

Fig. 7.10 Calibration of event-based simulation

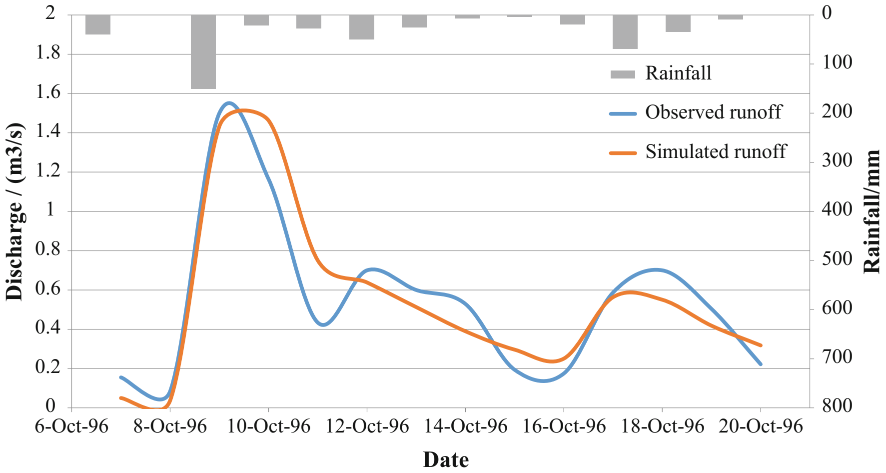

Fig. 7.11 Validation of event-based simulation

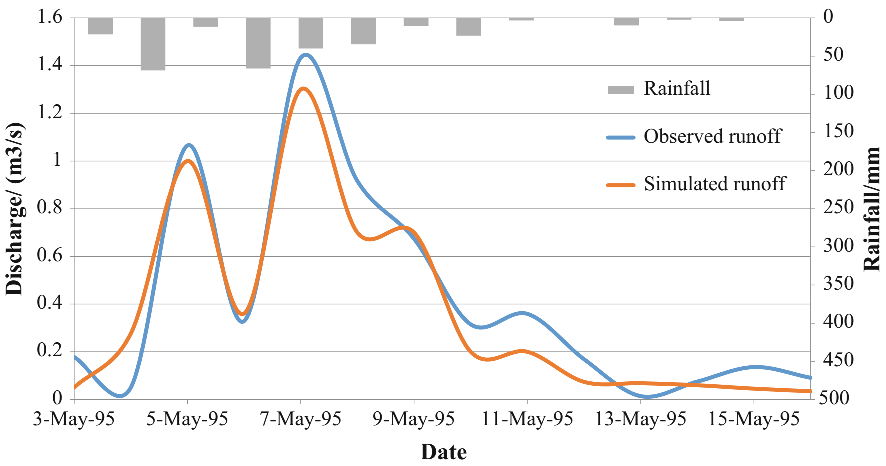

Fig. 7.12 Validation of event-based simulation

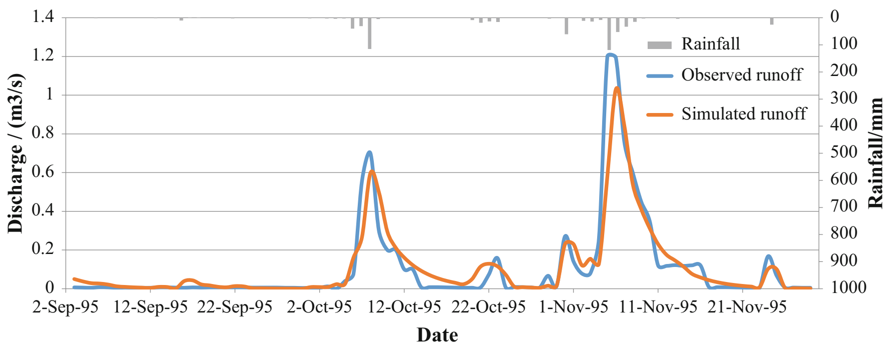

Fig. 7.13 Calibration of continuous simulation

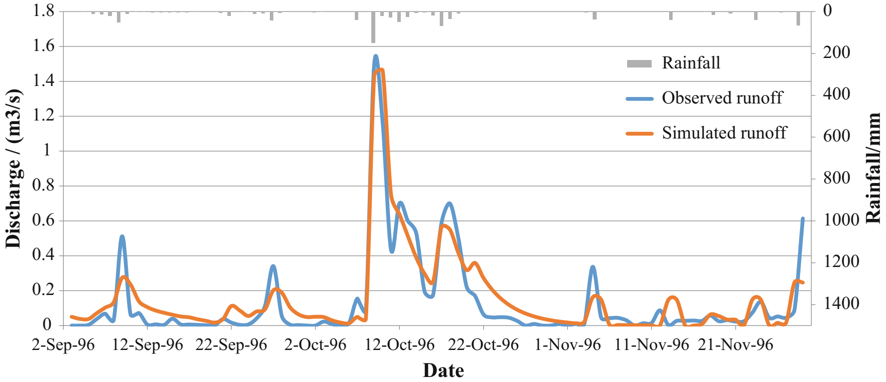

Fig. 7.14 Validation of continuous simulation

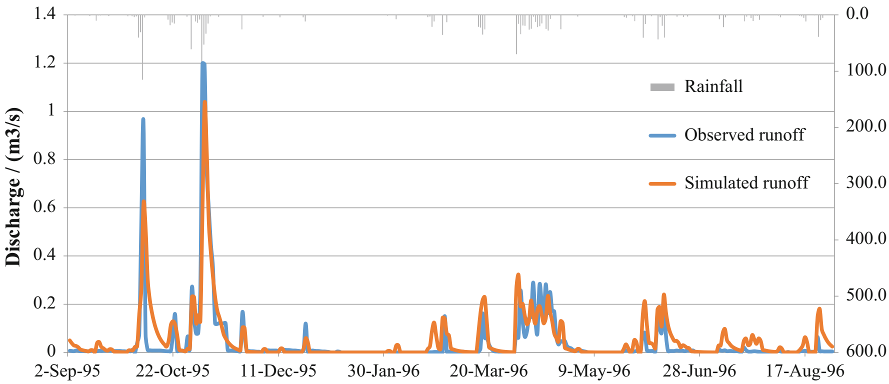

Fig. 7.15 Validation of continuous simulation

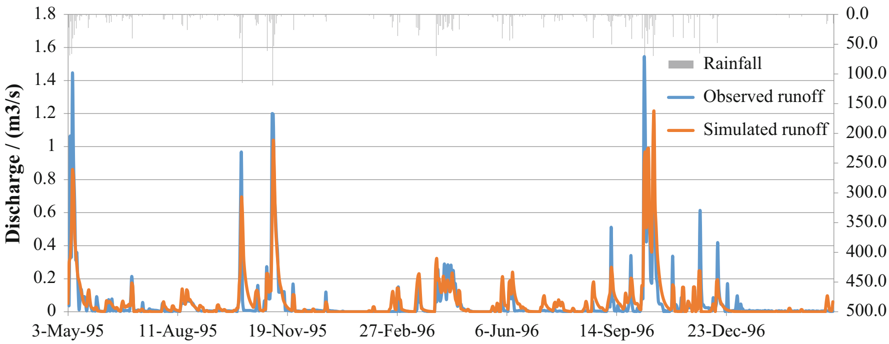

Fig. 7.16 Validation of continuous simulation

Table 7.3 Computed skill metrics for event-based and continuous simulation

	Period	*NOF*	R^2_{NS}	δ_b,
Event-based simulation	October–November 1995	0.20	0.95	0.20
	October 1996	0.26	0.86	1.64
	May 1995	0.28	0.92	12.0
Continuous simulation	September–November 1995	0.83	0.85	3.00
	September–November 1996	0.77	0.84	18.0
	September 1995–August 1996	1.69	0.73	33.0
	May 1995–March 1997	1.60	0.72	20.0

7.4.2.2 Calibration

HEC-HMS model was calibrated for isolated rainfall events and also for continuous rainfall. Observed daily rainfall and discharge during October–November 1995 was used for event-based model calibration. Skill metrics for simulated river discharge were computed, and the best fit with observed was obtained by adjusting model parameter values for moisture loss, runoff transform method, and baseflow processes of the HEC-HMS model. The rainfall and discharge in October 1996 and May 1995 were used to validate the calibrated event-based model. Rainfall and discharge data during September–November 1995 period was used to calibrate the continuous simulation of the model, while 3-month, 1-year, and 23-month time series during September–November 1996, September 1995–August 1996, and May 1995–March 1997 were used to validate the continuous model simulations.

The event-based simulations employed the initial and constant loss method to compute infiltration loss, while continuous simulations used the five-layer soil moisture accounting loss method. The initial and constant loss rate model requires the constant loss rate and initial loss to be specified. The soil moisture accounting loss method uses five layers to represent the dynamics of water movement in and above the soil. The layers include canopy interception, surface depression storage, soil, upper groundwater, and lower groundwater. The soil layer is subdivided into tension storage and gravity storage (Scharffenberg and Fleming 2006; US Army Corps of Engineers 2000). Implementation of both loss methods requires the soil properties of the subbasin. According to soil type and catchment properties in the basin, an initial loss of 30 mm and a constant loss rate of 1.0 mm/h and catchment imperviousness of 10% were used in initial and constant loss method. The above parameters were able to produce the best fit against observations. Parameters used for soil moisture accounting loss method are shown in Table 7.4.

Clark unit hydrograph was selected as transformation method where time of concentration and storage coefficient were selected as 3 h and 2 h, respectively, for the Clark unit hydrograph. The storage coefficient is used in the linear reservoir that accounts for storage effects (Scharffenberg and Fleming 2006).

Table 7.4 Summary of parameters used in soil moisture accounting loss method

Parameter	Value
Soil (%)	70
Groundwater 1 (%)	31
Groundwater 2 (%)	82
Canopy storage (mm)	23
Surface storage (mm)	5
Max infiltration (mm/h)	15
Imperviousness (%)	10
Soil storage (mm)	124
Tension storage (mm)	25
Soil percolation (mm/h)	31
Groundwater 1 storage (mm)	44
Groundwater 1 percolation (mm/h)	0.05
Groundwater 1 coefficient (h)	66
Groundwater 2 storage (mm)	201
Groundwater 2 percolation (mm/h)	0.42
Groundwater 2 coefficient (h)	30

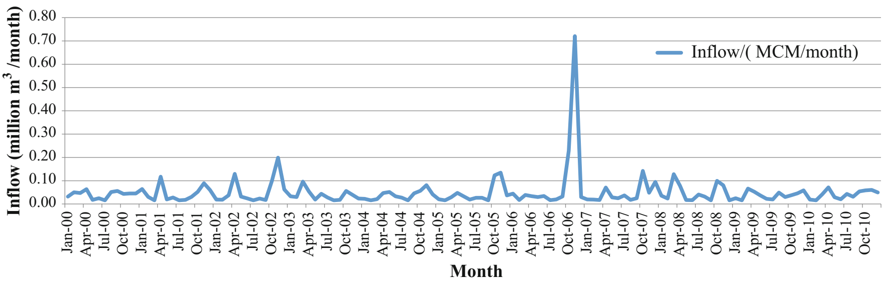

Fig. 7.17 Monthly inflows to Mellapoththa reservoir

Recession baseflow method was employed for both event-based and continuous simulations. The recession constant was set to 0.76 and ratio to peak was set to 0.5, while the initial discharge was set to 0.05 m^3/s after simulating several trials.

Calibrated and validated HEC-HMS model was applied to generate daily inflows to 136 small tanks in LB development area from their respective catchments.

Catchment areas, land use pattern storage capacities, command areas, natural streams, geological features, and cascades were identified by using relevant GIS data and digitizing techniques for all minor reservoirs augmented by the LB canal. Topographic, geologic, and land use data were collected from the digital data of the Survey Department of Sri Lanka. ArcGIS 9.3 was used for spatial analysis of the Deduru Oya LB region.

Figure 7.17 shows the calculated monthly inflow values for Mellapoththa reservoir. Figure 7.18 shows calculated monthly inflow values for Amunukole reservoir.

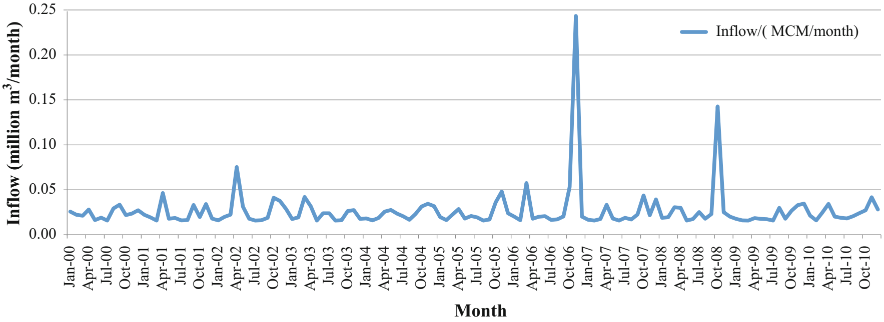

Fig. 7.18 Monthly inflows to Amunukole reservoir

7.4.2.3 Modeling of Flow into Deduru Oya Reservoir

Rainfall data at stations in the basin including Ridi Bendi Ela, Wariyapola, Millawa, Delwita, Batalagoda, Nikaweratiya, and Kurunegala stations were compiled for the analysis. Evaporation data from Batalagoda and Mahawa, which are the closest stations to the proposed reservoir site, were obtained from the Department of Meteorology, Colombo. Daily streamflow data was available at Moragaswewa gauging station and was obtained from the Department of Irrigation, Colombo. Also, streamflow data is available at Ridi Bendi Ela station in the report of Hunting Survey Corporation Ltd and Survey General (1963).

Streamflow data is available only at Moragaswewa from 1981 to 1989. Therefore, HEC-HMS model was applied to Deduru Oya basin above Moragaswewa (79.990° E, 7.700°N) which is located 32 km downstream to the Ridi Bendi Ela, hereafter referred to as DMW subbasin. DMW subbasin which is an upper basin of the Deduru Oya has an area of 1950 km^2 ranging from 30 m to 1280 m MSL extending from Moragaswewa to the central hills of Sri Lanka (Fig. 7.19). DMW subbasin of Deduru Oya basin covers 74% of whole Deduru Oya basin. DMW subbasin located between 7.320°N and 7.860°N latitudes and 79.990° E and 80.580° E longitudes is one of the major rice production basins in the country. The Deduru Oya of DMW subbasin flows through Matale and Kurunegala districts.

There are intra-basin diversions for irrigation systems in the basin. Part of water supplied for irrigation drains to the downstream of the irrigation systems. This drainage water eventually flows into the downstream reach of the Deduru Oya in the DMW subbasin.

7.4.2.3.1 Intra-basin Diversion to Magalla Reservoir

There is an intra-basin diversion from the Deduru Oya river flow for irrigated paddy cultivation to the right bank at its middle reach. A weir constructed across the river diverts water to unlined Ridi Bendi Ela canal of 21 km length and capacity of

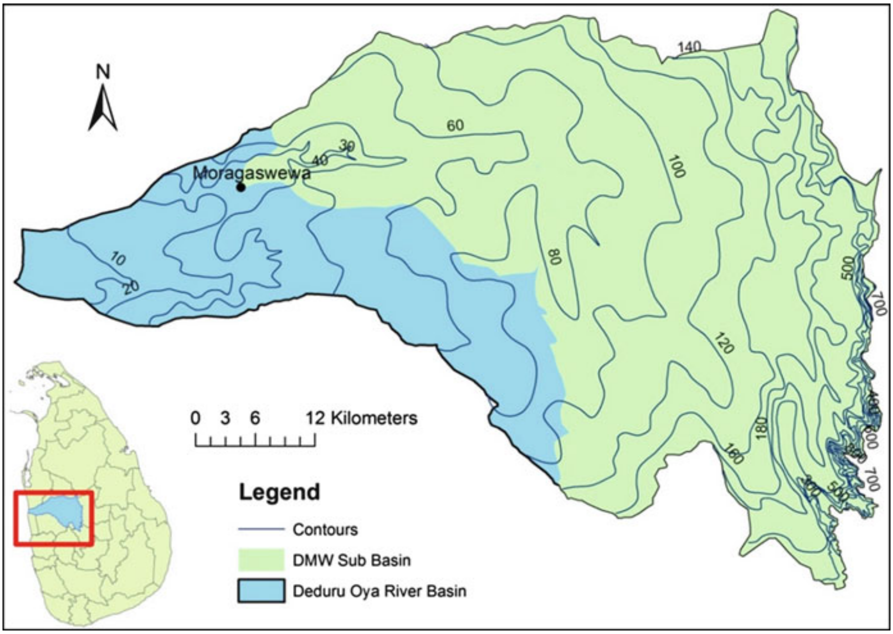

Fig. 7.19 Location and topography of the basin

Table 7.5 Capacities of Magalla reservoir outlet canals and irrigation area

Canal	Capacity (m^3/s)	Irrigation areas (ha)
RB canal	3.4	1792
LB canal	1.13	312
Center canal	0.43	120

4.25 m^3/s to Magalla reservoir at Nikaweratiya (Fig. 7.20). The weir diverts almost all flow of the Deduru Oya to the Magalla reservoir during low river flow months. The Magalla reservoir with a capacity of 9 million m^3 stores water for the irrigation requirements in downstream areas. There are 2224 ha of paddy lands cultivated presently under the Magalla reservoir irrigation system. The Magalla reservoir has its own catchment area of 32 km^2.

The Magalla reservoir has three irrigation canals: RB canal, LB canal, and center canal to distribute water. Capacities of the canals and the irrigable areas under each canal are shown in Table 7.5. The drainage water from the paddy fields at Magalla reservoir irrigation systems flows into the Deduru Oya at the upstream of Moragaswewa (Fig. 7.20).

For the application of HEC-HMS, the DMW subbasin which has an area of 1950 km^2 was divided into two subbasins: DRB subbasin of an area of 1400 km^2 above the irrigation diversion at Ridi Bendi Ela and the rest of the DMW basin

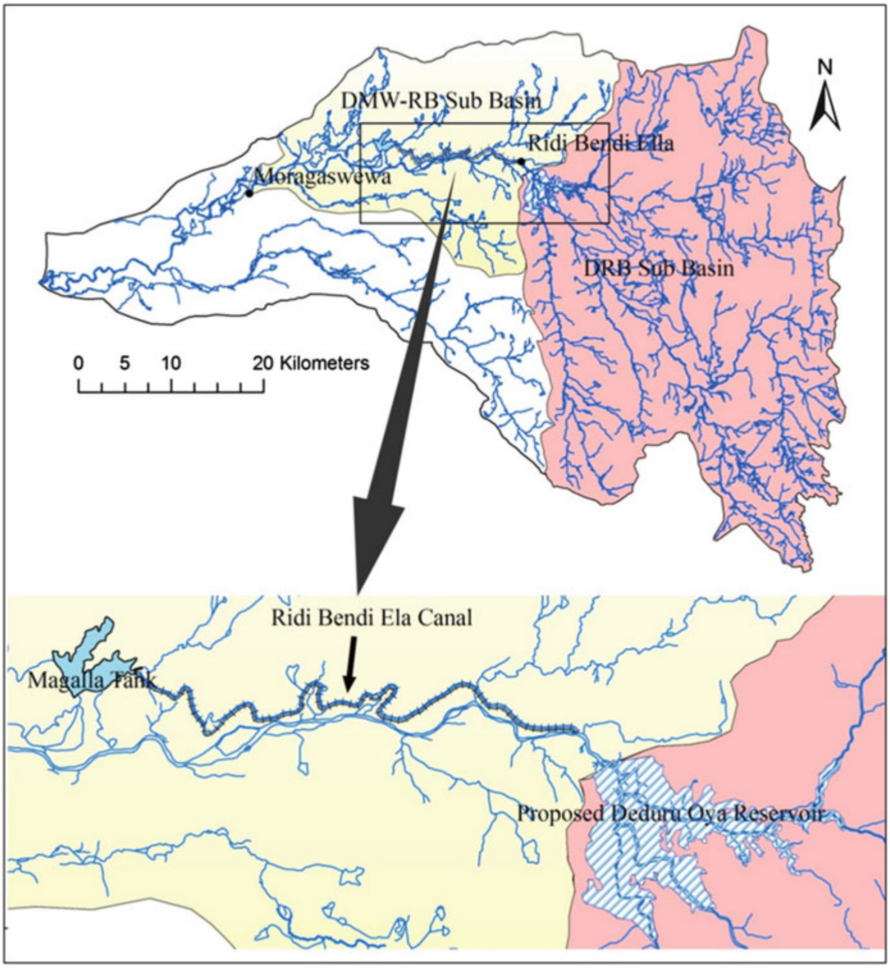

Fig. 7.20 Magalla reservoir and subbasins in the study area

(referred to as DMW-RB subbasin) of an area of 550 km^2 (Fig. 7.20). The schematic diagram of the HEC-HMS model setup is given in Fig. 7.21.

Ridi Bendi Ela canal was modeled as a diversion element, and Magalla reservoir was modeled as a reservoir element. The drainage flow from the irrigation systems under Magalla reservoir is modeled as a reach element.

Daily streamflow at the DRB basin outlet was estimated by HEC-HMS model application to the DRB basin. Diversion to Magalla reservoir from DRB basin outlet through Ridi Bendi Ela canal is 4.25 m^3/s or maximum available at the DRB basin outlet. The flow excess of 4.25 m^3/s is an inflow to the DMW-RB basin through Deduru Oya.

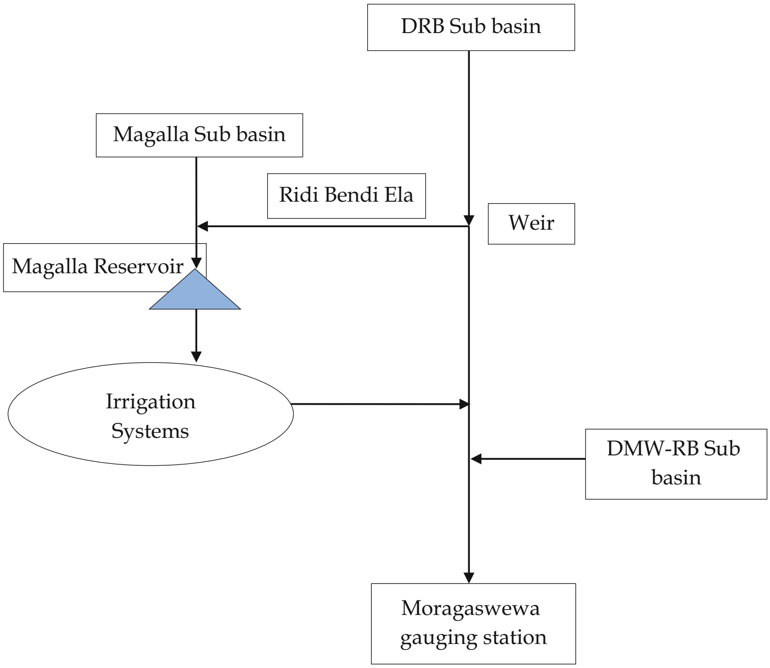

Fig. 7.21 Schematic diagram for modeling DMW subbasin

Magalla reservoir receives inflow from its own basin and from the Ridi Bendi Ela canal. Daily releases from Magalla reservoir for irrigation systems through the three canals depend on the irrigation requirements and available storage. Reservoir simulation was carried out to estimate the actual daily releases.

Irrigation requirements in the irrigation systems were estimated by CROPWAT model (Richard et al. 1998). Drainage flow from the irrigation systems was taken as 40% of the total release of Magalla reservoir through the three canals according to loss calculation and water balance study.

GIS data was used to identify stream paths, catchments, natural streams, land use patterns, geology, and soil types in the basin. Topographic, geology, and land use details were obtained in digital format from the Survey Department of Sri Lanka. The major portion of the soil in river basin was identified as reddish-brown earth (HWSD 2013; Mapa et al. 2005).

Daily rainfall was collected from seven stations in the basin (Fig. 7.22), viz., Kurunegala, Delwita, Wariyapola, Millawa, Ridi Bendi Ela, Batalagoda, and Nikaweratiya, for 20 years from 1980 to 2000. Monthly evaporation data for the same years for the agrometeorological station Mahawa was used in the study. The rainfall data and the evaporation data were obtained from the Department of Meteorology, Colombo. Discharge rating curves for Ridi Bendi Ela, LB, RB, and center canals of Magalla reservoir, discharge curve for Ridi Bendi Ela, and area-capacity-elevation curve for the Magalla reservoir were obtained from the Department of Irrigation. The only streamflow data available for the Deduru Oya is from

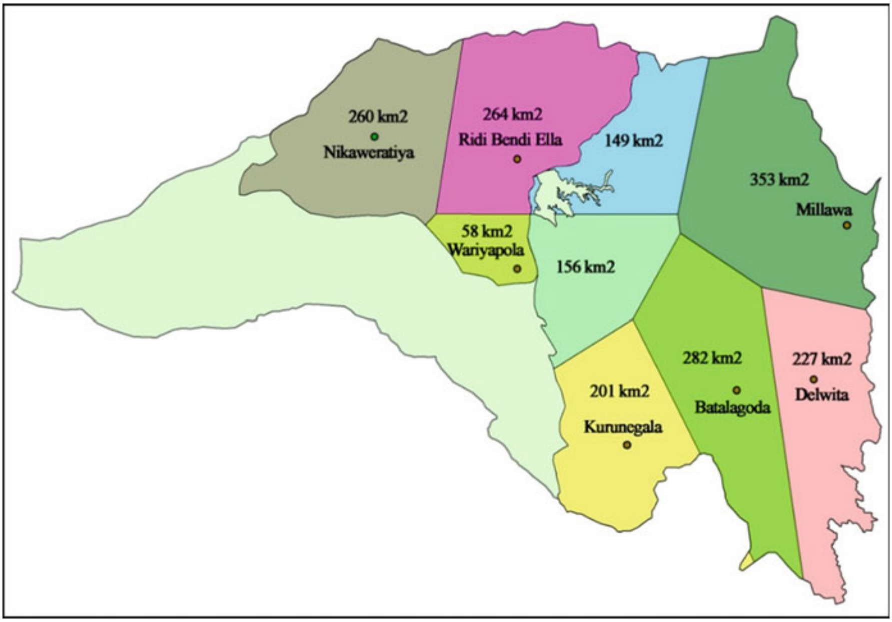

Fig. 7.22 Rain gauge stations and Thiessen polygon areas

1980 to 1989 at Moragaswewa gauging station. Daily flow data at Moragaswewa for the latest 3 years was used for model calibration and validation, viz., 3 months for calibration and 3 years for validation (Nash and Sutcliffe 1970). Normalized objective function (*NOF*), Nash-Sutcliffe efficiency (R^2_{NS}), percentage bias (δ_b), and root mean square error (*RMSE*) values were used as quantitative measures for the skill of simulations.

7.4.2.4 Model Calibration

Calibration for continuous modeling was carried out by using daily rainfall from October 1985 to December 1985. Soil moisture accounting loss method, Clark unit hydrograph transformation method, and recession baseflow method were utilized for continuous simulations. Muskingum routing method was used to route the flow through the canal.

Table 7.6 shows the values used for the parameters related to soil moisture accounting loss method for the subbasins. Tables 7.7, 7.8, and 7.9 show parameters related to Clark method, recession, and surface flow routing, respectively.

For the calibration period, which is from October to December 1985, simulated daily discharge values were compared with observed daily discharge values. Figure 7.23 shows the graphical distribution of simulated discharge against observed discharge. The values of *NOF*, R^2_{NS}, δ_b, and *RMSE* are equal to 0.30, 0.96, 4.88%, and 22, respectively.

Table 7.6 Summary of parameters used in soil moisture accounting loss method

Parameter	Value		
	Deduru upper basin	Magalla reservoir catchment	Moragaswewa sub-catchment
Soil (%)	70	70	70
Groundwater 1 (%)	46	46	46
Groundwater 2 (%)	82	82	82
Canopy storage (mm)	10	10	10
Surface storage (mm)	0	0	0
Max infiltration (mm/hr)	7	7	7
Imperviousness	50	45	42
Soil storage (mm)	123	123	123
Tension storage (mm)	60	60	60
Soil percolation (mm/hr)	1.3	1.3	1.3
Groundwater 1 storage (mm)	200	200	200
Groundwater 1 percolation (mm/h)	1.4	1.4	1.4
Groundwater 1 coefficient (h)	80	80	80
Groundwater 2 storage (mm)	200	200	200
Groundwater 2 percolation (mm/h)	1.3	1.3	1.3
Groundwater 2 coefficient (h)	1.5	1.5	1.5

Table 7.7 Time of concentration and storage coefficient for Clark method

Parameter	Value		
	Deduru upper basin	Magalla reservoir catchment	Moragaswewa sub-catchment
Time of concentration (hrs)	24	7	35
Storage coefficient (hrs)	33	12	40

Table 7.8 Recession baseflow parameters

Parameter	Value		
	Deduru upper basin	Magalla reservoir catchment	Moragaswewa sub-catchment
Initial discharge (m^3/s)	51	8	10
Recession constant	0.77	0.65	0.7
Ratio to peak	0.65	0.5	0.5

7.4.2.5 Validation

The time series data from October 1984 to 30 September 1985 (1 year) and October 1987 to September 1989 (2 years) were used for validation of continuous simulation. Validation results indicate that there is a good agreement between the observed and simulated flows. Table 7.10 shows the goodness of fitting between

Table 7.9 Muskingum routing parameters

Parameter	Value		
	Deduru upper basin	Magalla reservoir catchment	Moragaswewa sub-catchment
Muskingum *K*/(hr)	10	2	4
Muskingum *X*	0.2	0.2	0.2
Sub-reaches	2	1	2

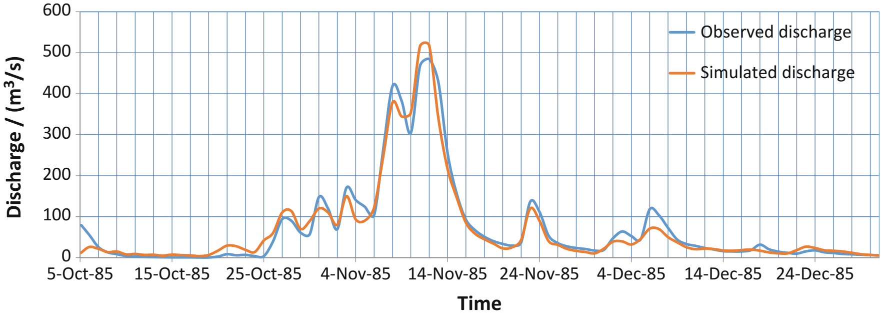

Fig. 7.23 Observed and simulated discharges at Moragaswewa for October–December 1985

Table 7.10 Goodness of fit for streamflow simulation

Event	*NOF*	R^2_{NS}	δ_b	*RMSE*
October 1984–September 1985	1.00	0.76	18%	25
October 1987–September 1989	1.00	0.7	17%	34

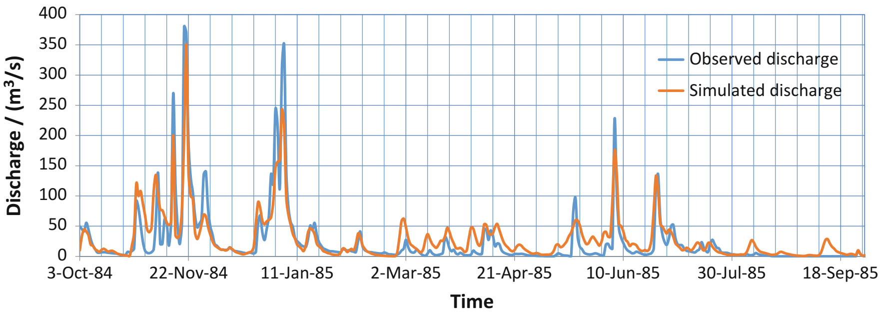

Fig. 7.24 Observed and simulated discharges at Moragaswewa for October 1984–September 1985

simulated and observed flow for validation periods, and the parameters fall within acceptable ranges. The observed and simulated discharge hydrographs are shown in Figs. 7.24 and 7.25, respectively.

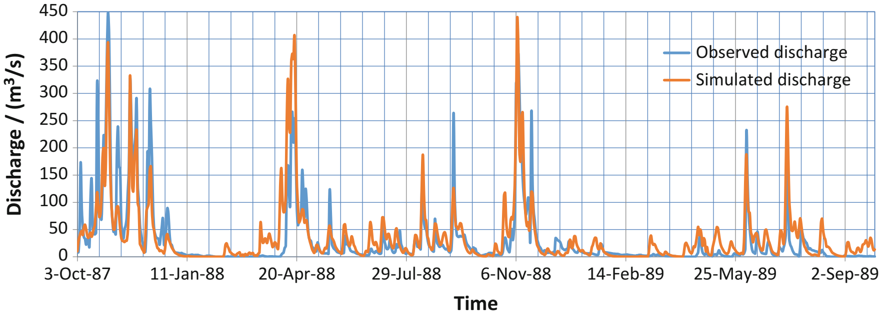

Fig. 7.25 Observed and simulated discharges at Moragaswewa for October 1987–September 1989

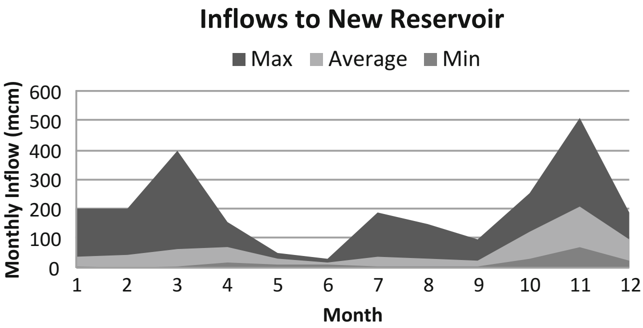

Fig. 7.26 Inflow to Deduru Oya reservoir

7.5 Results

Based on the hydrological model setup for the ancient tank catchments and Deduru Oya reservoir basin, it is possible to estimate the total inflows to both modern and ancient irrigation systems. Figure 7.26 shows the maximum, average, and minimum monthly inflows to Deduru Oya reservoir estimated from the 2000 to 2010 rainfall records. The inflow values show a large intra-annual variability of inflows as shown by inflow value changes from January to December. A large interannual variation is also observed as shown by the large differences among maximum, average, and minimum streamflows for the 2000–2010 period records. A similar trend is also observed in the inflows to ancient tanks as shown in Fig. 7.27.

A comparison of annual inflow shows a very high interannual variability as shown in Fig. 7.28 by the contrast among maximum, minimum, and average flows. The most striking feature, however, is the large difference of inflows to the new reservoir compared to the ancient irrigation system. Assuming about 30% of inflow

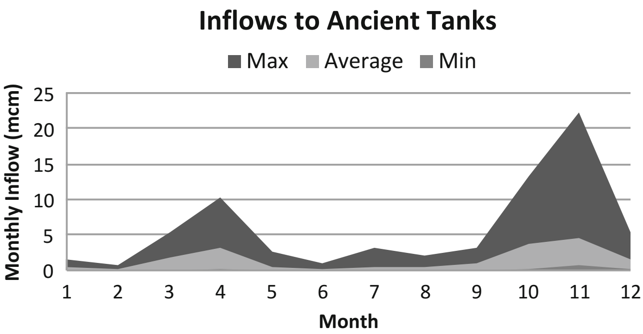

Fig. 7.27 Inflow to ancient irrigation tanks

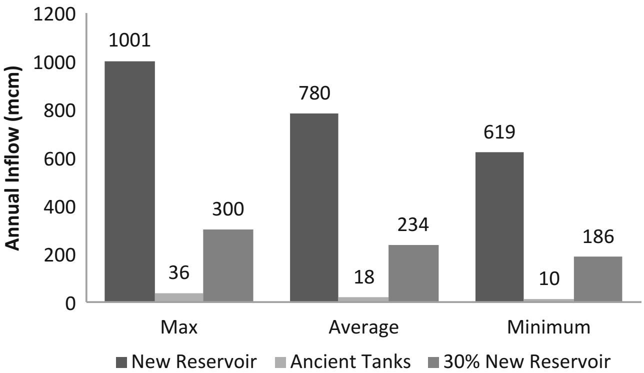

Fig. 7.28 Annual inflow into new reservoir and the ancient irrigation system

to the reservoir may be available for LB canal, the potential contribution from the new reservoir would be more than 10 times that entering ancient irrigation tanks. From these inflow estimates, we may expect that new reservoir alone would be supplying most of the irrigation water requirements in an average year, and the role of ancient irrigation system could function more for building social harmony and to absorb unexpected shocks associated with climate change to form a resilient system.

7.6 Summary

Water availability for the Deduru Oya LB canal development region from the traditional tanks and from the Deduru Oya reservoir was investigated.

HEC-HMS rainfall-runoff model was set up for modeling event-based and continuous streamflow into the Tittawella reservoir. Predictions were compared with observations, and skill of simulations is satisfactory, as depicted by *NOF*, R^2_{NS}, and $\delta_{b,}$ for both calibration and validation periods in event-based and continuous simulations. Moreover, the results of continuous simulations show that the calibrated model is capable of capturing the seasonal characteristics of streamflow satisfactorily. Runoff from LB reservoir subbasins were calculated by using corresponding parameters of Tittawella reservoir model.

HEC-HMS rainfall-runoff model was developed for part of Deduru Oya basin with intra-basin diversion and storages. Simulation results agree reasonably well with observed discharges as described by *NOF*, R^2_{NS}, δ_b, and *RMSE*. The results show that the calibrated model is capable of capturing the seasonal characteristics of Deduru Oya flow satisfactorily. By using long-term daily rainfall forecast, the model with the calibrated parameters can be used for estimating inflow to the Deduru Oya reservoir as well as flow at the Deduru Oya basin outlet. The study demonstrates potential HEC-HMS application in flow estimation from tropical catchments with intra-basin diversions and irrigation storages. The model developed is a useful tool for water management in the Deduru Oya basin.

The hydrological models are very useful tools that can be used for water resource development and irrigation water management under changing climate in the LB development area of the Deduru Oya project.

Through the hydrological modeling of the entire LB canal area, it was possible to clarify the water resources available for irrigation from both ancient irrigation system and the new Deduru Oya project. The simulation carried out for the past 10 years reveals that the Deduru Oya reservoir project which has planned to operate LB canal irrigation management incorporating the existing small irrigation reservoirs will be able to supply the water demand for LB development area for paddy cultivation with a high degree of reliability.

References

Agrawal A (2005) A data model with pre- and post processor for HEC–HMS, MSc Thesis, Dept. of Civil Engineering, Texas A & M University. http://hdl.handle.net/1969.1/2550

Attygala N (ed) (1948) History of Ceylon, vol 1. University of Ceylon, University of Vidyalankara, Ceylon, pp 500–510

Brohier RL (1935) Ancient irrigation works in Ceylon – part III. Ceylon Government Press, Colombo, pp 1–9

Cūlavaṃsa (1929) *Sri Lankan History* – English translation by Wilhelm Geiger, Asian Education Service, New Delhi

De Silva M, Weerakoon SB, Herath S (2014) Modeling of event and continuous flow hydrographs with HEC–HMS: case study in the Kelani River Basin, Sri Lanka. J Hydrol Eng 19(4):800–806

Halwatura D, Najim MMM (2013) Application of the HEC-HMS model for runoff simulation in a tropical catchment. J Environ Model Softw 46:155–162

Harmonized World Soil Database (HWSD) (2013) http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/) Accessed 6 Nov 2013

Herath S, Mohri H, Wong P, Mishra B, Sampath DS, Weerakoon SB, Atapattu S, Woldie D (2013) Traditional and modern agriculture mosaic system for improving resilience to global change. Conference on Sri Lanka–Japan collaborative research (SLJCR 2013), University of Peradeniya, Sri Lanka, p 125

Hunting Survey Corporation Limited-Toronto and Survey General of Ceylon (1963) A report on a survey of the resources of the Kelani-Aruvi area Ceylon, vol II. Ceylon Government Press, Ceylon, pp 124–125

Irrigation Department (1998) Hydrology of small catchments, vol II. Hydrology Division, Colombo

Jinapala K, Somaratne PG, Perera LR, Makin IW, Bandaragoda DJ (2003) Multi-level participatory consultative approach for institutional change in River basins, Lessons from Deduru Oya case in Sri Lanka, IWMI research report 59. International Water Management Institute (IWMI), Colombo

Mahāvaṃsa (1912) *Sri Lankan History* -English translation by Wilhelm Geiger, Pali Text society, Oxford University Press

Mapa RB, Dissanayake AR, Nayakakorale HB (2005) Soil of the intermediate Zone of Sri Lanka: morphology characterization and classification. Soil Science Society of Sri Lanka, Peradeniya

Nash JE, Sutcliffe JV (1970) River flows forecasting through conceptual models. Part 1 a discussion of principles. J Hydrol 27(3):282–290

National Atlas of Sri Lanka – Survey Department (2007) National atlas of Sri Lanka, 2nd edn. Survey Department, Colombo, pp 60–63

Nicholas CW (1954) The irrigation works of King Parakramabahu I. Ceylon Hist J IV:52–68

Parker H (1889) Irrigation in the north western provinces report on the proposed Deduru Oya project, vol III. Government Printers, Colombo

Pre-feasibility study report of Deduru Oya and Mee Oya river basins Development Project (2001) Planning branch. Irrigation Department, Colombo

Richard GA, Luis SP, Dirk R, Martin S (1998) Crop Evapotranspiration-guidelines for computing crop water requirements, Publication no. 56 of the irrigation and drainage series of FAO. FAO, Rome

Scharffenberg WA, Fleming MJ (2006) Hydrologic modeling system HEC–HMS user's manual. US Army Corps of Engineers, Institute for water resources, Hydrologic Engineering Centre, Davis

Somaratne PG, Jinapala K, Perera LR, Ariyaratne BR, Bandaragoda DJ, Makin IW (2003) Developing effective institutions for water resources management: a case study in the Deduru Oya Basin, Sri Lanka, working paper 58. International Water Management Institute, Colombo

US Army Corps of Engineers (2000) HEC-HMS technical reference manual. Hydrological Engineering Center, Davis

Weerakoon SB, Herath S, Tamai N (2001) River basin based paddy extent estimation considering irrigation systems in Sri Lanka. International symposium on LUCC contribution to Asian environmental problems, Tokyo

Chapter 8
Mosaic of Traditional and Modern Agriculture Systems for Enhancing Resilience

Srikantha Herath, Binaya Mishra, Pearly Wong, and S. B. Weerakoon

Abstract There are many traditional agricultural production systems in Asia that have resulted not only in outstanding landscapes, maintenance of agricultural biodiversity, indigenous knowledge, and resilient ecosystems development but also provided economic, environmental, and social goods and services over thousands of years. With growing population and economic aspirations, many of these systems are being replaced by modern agriculture systems that are designed for efficiency and large-scale development. However, there is also a growing realization that we should in some form preserve these valuable repositories of indigenous knowledge for climate change adaptation, biodiversity conservation and land management, and the rich culture they spawned. Different approaches such as World Cultural and Natural Heritage sites, in particular World Cultural Heritage Landscapes of UNESCO, or the Globally Important Agriculture Heritage Systems of FAO attempt to preserve and showcase representative production sites from these systems. However, they cannot be upscaled to cover the vast populations still engaged in them. In this paper, we investigate the feasibility of fusing the traditional and the modern systems through building mosaics of traditional and new systems.

In this article, we have studied the Deduru Oya irrigation project which provides an ideal ground for research and experimentation of integrating modern irrigation and ancient irrigation systems to improve cropping intensity and resilience. The simulation carried out for past 10 years reveal that this project planned to operate LB canal irrigation management incorporating the existing small irrigation tanks will be able to supply the water demand for LB development area for paddy

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K. Takeuchi et al. (eds.), *Resilient Asia*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56597-0_8

cultivation without failure. While the modern system can adequately meet the irrigation demand, the integration of existing distributed small tanks provides resilience for extreme drought conditions and the much-needed macro-microscale integration with autonomy at microscale.

Keywords Traditional irrigation system · Deduru Oya project · Hydrological modeling · Resilience

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8.1 Introduction

Asia is home to a number of traditional agricultural landscapes that have withstood climate variability and varied societal changes for over 1000 years. These systems have resulted not only in outstanding landscapes, maintenance of agricultural biodiversity, indigenous knowledge, and resilient ecosystems development but also, above all, in the sustained provision of economic, environmental, and social goods and services. In addition to the social and environmental importance of these systems, they are valuable repositories of indigenous knowledge for climate change adaptation, biodiversity conservation, and land management. The ancient irrigation systems in the dry zone in Sri Lanka are an example of such sustainable agriculture systems, which helps the rice agriculture adapt to the variable and seasonal conditions of monsoon rainfall where rainfall is concentrated in 3 months of the year. In response to this climatic conditions, irrigation systems consisting of large number of interconnected reservoirs (*wevas* or tanks) evolved during the period from the third century BC to twelfth century AD. It is widely accepted that the ancient irrigation system in the dry zone of Sri Lanka was largely developed during the period up to the twelfth century. The system faced a decline from thirteenth century to nineteenth century (Panabokke 1999) due to numerous reasons including poor soil conditions, malaria epidemic, political instability, etc., although the system did not completely collapse. These systems still function as a crucial element in agricultural sector of the dry zone supporting a large farmer population. They also constitute one of the richest sources of wetland biodiversity in the country. However, the productivity of such systems is not high enough now to support the growing population and aspirations of modern-day lifestyles by their agricultural output alone.

Now, modern irrigation schemes have replaced much of the old tank-based systems. These modern irrigation schemes with centralized management are highly productive and are designed to efficiently cater to high demands of present-day populations and economic growth. However, these systems are highly optimized and run the risk of failure with changes to existing climate and ecosystem state. In addition, much had been lost in social harmony, human-nature coexistence, and system resilience. In the present-day context, farmers are organized into legally recognized autonomous organizations. Each irrigation scheme has a project management committee (PMC) consisting of representatives of the farmer organizations and the government agencies concerned with irrigated agriculture and water allocation. Water allocation is discussed and decided through meetings at PMC. This system does not make farmers an integral part of the whole system.

There have been a number of large-scale development projects involving reservoirs and diversions providing irrigation to the dry zone recently (most rapid developments during the 1970s and 1980s), making it difficult to ascertain their long-term impact on ecosystems, biodiversity, and man-made habitats associated with tanks. The ancient systems could provide valuable insights to make them sustainable and attractive and be very useful in the quest of various development alternatives, especially for sustainable green development pursuits. How can the characteristics of ancient systems be incorporated in today's infrastructure management systems? What lessons can be learned from the past to design community-based management system supported by a regional layer that address macro level management requiring higher level of technical competency followed by central organizational oversight? How can we incorporate the lessons from these systems to integrate reservoirs to local communities, not only as efficient water storage and management systems as designed today but also a host of other services for biodiversity, social harmony, aesthetic beauty, and cultural activities? This paper investigates the viability of a mosaic system consisting of modern and ancient systems to improve overall resilience of the system and improve livelihoods to all farmers through the increases in productivity.

8.2 Ancient Irrigation Systems of Sri Lanka

8.2.1 Description of the System

The ancient irrigation systems in Sri Lanka were perfected through consistent improvement and construction over 1600 years and cover most of the north central zone of Sri Lanka with intricate networks of small to gigantic reservoirs (tanks) that numbered around 15,000 connected through a series of feeder canals that brought water for yearlong rice cultivation in the dry zone. Figure 8.1 shows a distribution of some of the larger tanks in the North Central Province of Sri Lanka. Highly sophisticated engineering skills have been developed with the evolution of the systems that include first large-scale sluice gates and near-zero gradient irrigation canals. Maintenance of the systems also requires a high level of understanding of hydrology and hydraulics as applied to large systems. This hydraulic civilization has successfully bridged micro and macro systems where small village reservoirs were linked up with massive reservoirs in intricate hydraulic systems. Brohier (1934, 1937a) identified that there is a chain-like structure in organization of small tanks in Sri Lanka and their relationship with large ancient reservoirs and waterways. Madduma Bandara (1994) coined the term *cascades* to identify this pattern where water from upstream tanks was successively stored and released to those of downstream. These small cascades are linked to large reservoirs and giant feeder canals to form extremely complex large irrigation systems.

Brohier (1934, 1937a, b) explained the evolution of the tank systems as starting from a stage where rainwater tanks were built and water bailed out, followed by small tanks and canals followed by the 3rd stage where large reservoirs were built by submerging some small tanks. The final or the fourth stage was where the weirs across major streams were built and large-scale canals such as Yoda Ela were built to enable transboundary water distribution, which enabled water transfer beyond natural catchment boundaries.

Mendis (1986) presented an alternate view proposing that rainfed farming to irrigated farming evolved through the construction of river diversion works, followed by invention of sluice and construction of small, medium, and large

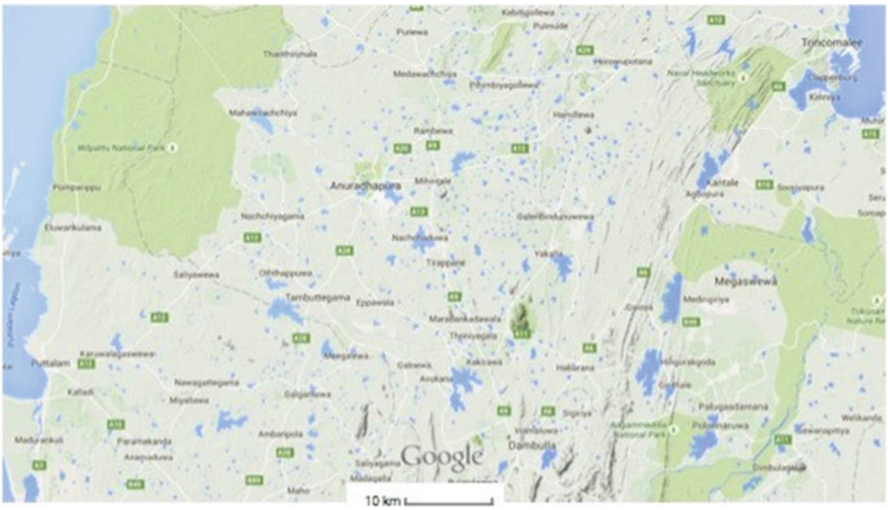


Fig. 8.1 Shapes of various sizes in blue color show the distribution of large number of irrigation tanks in the North Central Province of Sri Lanka (Source: Google Maps)

reservoirs, first across non-perennial waterways and, finally, large reservoirs across perennial services. This view also helps to appreciate the collection and use of rainfall-runoff in-between source reservoirs by single bank contour canals of the ancient irrigation system.

The technical breakthrough that enabled the construction of large irrigation systems in Sri Lanka is the invention of the "valve tower" or the "valve pit." Sir Henry Parker, a British engineer with the irrigation department who was entrusted with rehabilitation of ancient irrigation systems in mid-1800, describes the skills and inventions that went to the development of ancient tanks as follows: "It may be assumed, that the formation of all reservoirs of a class with embankments much higher than those of simple village tasks was originally due to the constructive genius of the Sinhalese; they were the first inventors of the valve-pit, more than 2100 years ago" (Parker 1909). This construction made it possible to use a single sluice gate to distribute water to paddy fields at any reservoir water level. However, it cannot accommodate high volumes associated with large reservoirs. The "bisokotuwa" has been developed for this purpose (Avsadahamy 2003). Sir Henry Parker (1909) describes the still intact bisokotuwa of "Pawatikulam tank," which had performed its duties continuously for over 2100 years.

The salient feature of irrigation system is the tank cascades in which water from upstream tanks is successively stored in those downstream in a catchment (Fig. 8.2). Each cascade has a number of village tank units each with a small reservation catchment, the reservoir, a strip of trees downstream of the reservoir that act as a windbreaking barrier, paddy fields, and the village (Fig. 8.3). The small tank cascades are then linked to large reservoirs and giant feeder canals to form extremely complex large irrigation systems. The system of tanks, paddy fields, and canals are so well integrated and interwoven with the natural environment that it is difficult to identify tank systems as man-made structures.

One of the remarkable features of the tank systems is their sheer density. Panabokke et al. (2002) have identified slightly over 15,000 ancient irrigation tanks as shown in Fig. 8.4 of which about a half are still functioning. Each grid in the figure represents one topo sheet covering 950 km^2. The distribution shows the highest tank density to be in the North Western Province (NWP) at about one tank per each 1.2 km^2, while the lowest tank density is recorded in the Eastern Province (EP) at one tank per 12 km^2. For NCP and SP provinces, the average density is found to be around one tank per 2.6 km^2. An analysis of tank distribution by each province shows that it is a function of both rainfall and the population density. While it is not clear if all the tanks were in operation at any given time, hydrological studies assuming typical runoff coefficients of small tank catchments at 0.15–0.3 have shown that the catchment areas are not adequate to supply inflows to all the tanks to irrigate the command areas under them. For example, Sakthivadivel et al. (1996, 1997) have observed that only 104 cascaded out of 240 cascades had adequate catchment area to supply adequate runoff that would ensure at least a 75% cropping intensity.

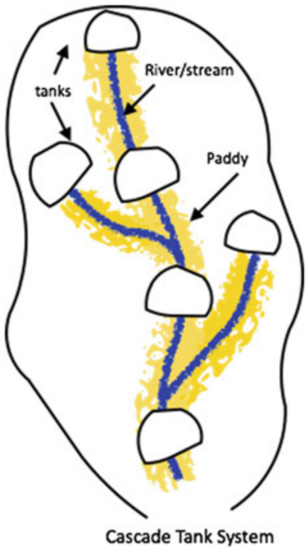


Fig. 8.2 Schematic representation of a tank cascade

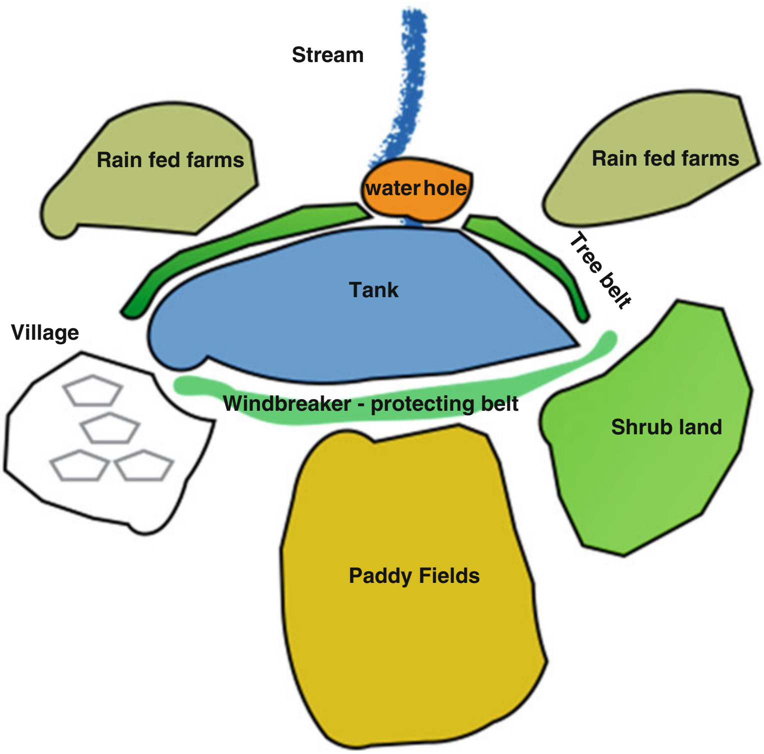
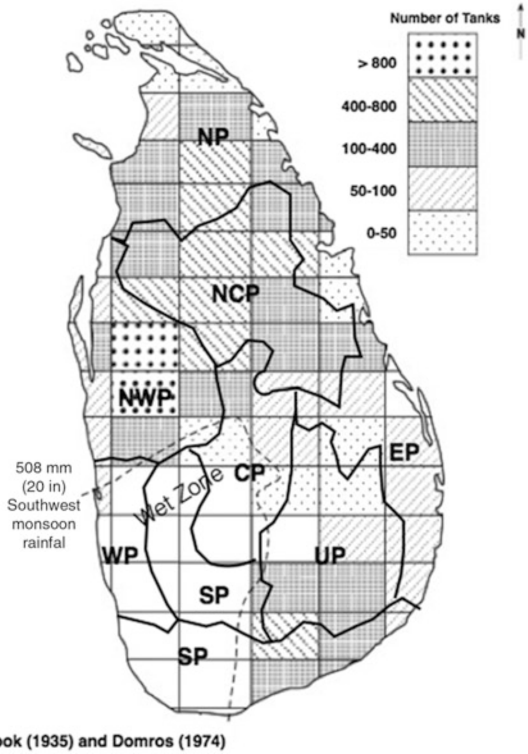


Fig. 8.3 Schematic diagram of the layout of a village tank unit

Fig. 8.4 Distribution of ancient irrigation tanks in Sri Lanka (Source: Panabokke et al. (2002)



8.2.2 Goods and Services Provided by the System

While the primary service provided by the tanks was the storage of rainfall to enable year-long rice growing with two seasonal crops, the tanks provided a number of other services. They made the micro-climate pleasant and cool and enabled bio- and agrodiversity. The tanks also served as the common bathing place for the village and the meeting point for the village described in Figs. 8.5, 8.6, 8.7, and 8.8.

Some of the tanks termed *Olagama* tanks were operated for recharging and stabilizing groundwater, another type of tanks termed *Kuluwewa* have been constructed for sediment control, and *Godawala* were used as water holes that provided access to village cattle and animals, birds, etc., following the Buddhist teaching that we are not "owners" but are the "custodians" of common resources to which all living entities have equal rights.

Most importantly the independence provided the ancient tanks through to each village has paved the way for a unique decentralized social system in Sri Lanka, where farmers had the highest social rank. The development of tank irrigation system was a crucial element in the social organization and cultural traditions in the dry zone. Numerous villages in the dry zone are having names synonymous with the name of the village tank. The highly distributed nature of this "water resource" and

Fig. 8.5 Am ancient irrigation tank

Fig. 8.6 Embankment of a tank

Fig. 8.7 Irrigation canals

Fig. 8.8 Bathing and socializing at a tank

the sheer number density had no doubt contributed to the shaping of the social structures of people that built, managed, and reaped benefits of them. The nature of the system encourages a much-decentralized mode of water governance at the same time emphasizing the importance of interrelationships and cooperation at larger scales.

Sri Lanka's lowland also features a number of very large historical reservoirs that are believed to be the products of a centralized state bureaucracy. When the states that supported them collapsed (after thirteenth century), these works were also ruined. However, the village tanks did not perish because they were constructed, managed, and maintained by the respective villagers. The linkage between the macro systems that produced the engineering innovation such as sluice gate and the village-level tanks that benefitted from such large-scale diversions has not been clarified adequately so far. There seems to have existed a "technocrat clan" that had the technical engineering knowledge and managed macro systems (Avsadahamy 2003) who may have benefited from state sponsorship, whereas the village tanks were operated and managed by elected members of the village community. It is believed that there had been a sophisticated system of shared responsibility and social equity developed around the village tank system. Until the colonial government initiated irrigation department in the 1860s, in fact, the management of village tanks completely remained on the hands of the locals.

Sri Lanka's ancient history provides several examples where the state's authority was effectively challenged and sometimes overrun by the common opinion. In addition to cultural and religious factors, historians increasingly see a contribution from the very decentralized and independent nature of the village tank systems toward the freedom of thinking. In fact, in the ancient history of Sri Lanka (particularly the early period of the second millennium), there are occasions showing a competition between the independent, self-sufficient villages and the desire of central authorities to consolidate them into state. Study of the history of Sri Lanka does not reveal evidence that a centralized bureaucracy ever even existed to run the country's irrigation works (Leach 1959). The necessary maintenance work was organized by the villagers themselves: there was never a centralized bureaucracy to direct such work or to ensure that it was carried out (Goldsmith and Hildyard 1984). It is reasonable to assume that the social system organized around the village tanks in ancient Sri Lanka was significantly different from the feudalism in the medieval Europe and many others elsewhere in the world. Understanding this unique and sustainable way of life is also as important as the scientific, economical, and ecological aspects of the ancient tank systems.

8.2.3 Threats and Challenges

During the early nineteenth century, the colonial government of the time did not allow the people to restore or repair their sluices or tanks, but later identified the importance of the tank system for the human livelihood in the dry zone (Levers

1890). However, the poor knowledge on the function of the systems had led to either ignorance or unplanned disruption of the ancient tank systems during large-scale irrigation development projects during the twentieth century. As the centralized large-scale schemes were considered to be more efficient than the decentralized small systems, a number of small tank cascades were replaced by large reservoirs and high capacity feeder channels.

However, the modern development has not been able to capture the harmony between local and regional hydrological characteristics that the older small cascade tank systems and ancient large reservoirs could capture so admirably. One of the examples is the function of the giant feeder canals, which Brohier (1937b) describes in relation to one such canal as

> The Jayaganga, indeed an ingenious memorial of ancient irrigation, which was undoubtedly designed to serve as a combined irrigation and water supply canal, was not entirely dependent on its feeder reservoir, Kalaweva, for the water it carried. The length of the bund between Kalaweva and Anuradhapura intercepted all the drainage from the high ground to the east which otherwise would have run to waste. Thus the Jayaganga adapted itself to a wide field of irrigation by feeding little village tanks in each subsidiary valley, which lay below its bund. Not infrequently it fed a chain of village tanks down these valleys – the tank lower down receiving the overflow from the tank higher up on each chain.

Figure 8.9 shows a modern feeder canal that is entirely dependent on the feeder reservoir as it shuts off the valley drainage by the high embankments on both sides of the canal. In contrast Fig. 8.10 shows the ancient feeder canal, which is now located a few tens of meters below the modern construction, having one embankment open to catch the runoff and following the contour lines that result in very low velocity and minimum loss of command area. The multifaceted functionality of ancient systems has given rise to a renewed interest to scientifically understand the function of the tank systems in recent times. The ancient irrigation systems have been developed and constructed over 1600 years, and the collective wisdom of those long years, in addition to the natural and social selection process that must have eliminated the unsustainable practices, should be embedded in the remaining systems. It is, therefore, very important to rehabilitate and scientifically understand their functions and services adequately.

The Minneriya Tank, built in 227 AD with a circumference of 32 km and with a capacity of 136 million cubic meters, has been irrigating farms uninterrupted till present. The operation and maintenance know-how of such reservoirs were lost in the wars when those entrusted with the maintenance of large tanks were killed and the governance systems collapsed in the sixteenth and seventeenth centuries. Whatever remained was lost during the colonization and modernization of the last couple of centuries. It is a great challenge to search, uncover, and combine whatever knowledge that remain with isolated individuals to understand the ecological resilience of this great heritage.

Fig. 8.9 A modern feeder canal with paved embankments on both side and steep gradient

Fig. 8.10 An ancient feeder canal close to the modern one in Fig. 8.9, with a single bank that traps the local inflow and slow velocity as it is a contour canal that retains a large command area

8.3 Methodology

Resilience building needs to be viewed holistically considering various challenges and identifying approaches that build resilience in various sectors. In this research we adopt the framework shown in Fig. 8.11 (Herath 2011), where the global change challenges such as climate change, land cover change, population increase, economic growth targets, and globalization are viewed as drivers that bring about challenges. They are to be addressed by strengthening ecological, social, and economic resilience of the system. In this research we addressed the (a) ecological resilience through the integrated water resources management in a mosaic of "old" and "new" water infrastructure, (b) social resilience through developing a framework for farmer associations at village level to interact with centralized water management authorities for basin-wide resource allocation and management, and (c) economic resilience through analysis of economic benefits of crop diversification.

In this paper only the results of section (a) and (b) are discussed as they are directly relevant to the "mosaic" concept.

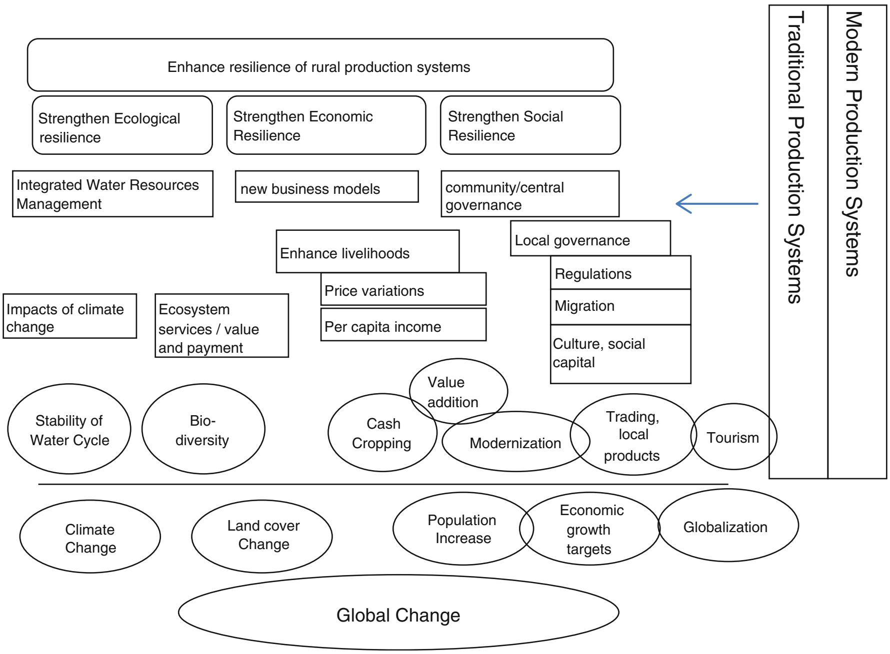


Fig. 8.11 Framework for developing strategies for building resilience in rural production systems

8.3.1 Modeling Water Allocation in Ancient and Modern Reservoir System

For the study Deduru Oya basin is selected as a new reservoir was being constructed in the basin, which is the sixth largest river basin in Sri Lanka. The basin also has the largest number of village tanks in the country. It has been decided that the left bank (LB) canal of the new reservoir would feed the ancient irrigation tanks in addition to directly providing irrigation to new land. The command area under ancient tanks on the left bank side is often affected by prolonged droughts, and in some years farmers cannot even cultivate a single crop due to lack of adequate water in the tanks. The supply of water to the tanks sometimes takes the form of drop-in takeout pattern where the LB canal from the main reservoir would feed an ancient tank from one side and then pick up from the other side. On other occasions, distribution canals will feed the tanks. At first a lumped system was analyzed where a number of adjacent tanks were combined to form tank groups for the purpose of analysis. However, due to the varied storage levels and the water receiving mechanisms, it became clear that individual village tanks need to be modeled with the central reservoir for the purpose of deriving optimal water allocation plans and identifying vulnerable points in the system. Therefore, the whole system comprising of 145 distribution nodes was modeled to derive water allocation planning and assessing water resources. In order to assess the effectiveness of the stand-alone and combined systems, the following scenarios were simulated:

- Ancient village tanks only under normal climatological conditions
- New reservoir only under normal climatological conditions
- New reservoir only under dry weather conditions
- New reservoir and ancient village tanks under dry conditions

Inflows to each ancient reservoir were modeled independently, and the combined system under the irrigation demand was modeled with WEAP model to estimate water allocation quantities.

8.3.2 Water Management in Ancient and Modern Reservoir System

Water management in the combined system requires special attention. Once the water allocation determines the water issues to and from each village reservoir and the LB canal, careful consideration is needed in water management according to allocation plan and available resources. Under normal operations, the irrigation department will be responsible for issuing water at each distribution canals to be managed by farmer associations. In the ancient reservoirs, an appointed villager is responsible to allocate water according to the norms adopted by the community. These village-level operations are only concerned with the management of water within the command area of their village tank. There is no water optimization among the tanks in a cascade. The downstream tanks would depend on the spillage from upstream, inflow from their tank catchment, seepage from upstream, and the return flows from the upstream paddy fields to supplement the water in their tanks. However, once the LB canal is directly linked to a particular tank, it is important that they understand that they are responsible for ensuring sufficient flow to cascades downstream of the LB canal. This means the farmers have to be trained in quantification and managing the amount of water they are allowed to use. If these measures are not implemented, the irrigation department will have to take over the water issue from the ancient tanks as well to ensure water management is carried out according to the allocation plan. However, that would defeat the purpose of reviving the ancient tanks system. Therefore we have studied different types of water allocation systems and concluded the bulk water allocation system in Mahaweli system H is an appropriate water management system for Deduru Oya scheme. The bulk water allocation approach basically adopts a mechanism for dividing water in an irrigation canal system equally among farmers considering the available amount of water for a farmer group is a fixed quantity as in a local reservoir. A detailed description of the system is given in Sect. 8.8. A researcher spent nearly 2 months in the field discussing with farmers and farmer associations to identify principles and measures required to be adopted in the basin for the water management of the mosaic system.

8.4 Water Allocation in the Mosaic System

8.4.1 Deduru Oya Project Description

Recently, the government of Sri Lanka has been emphasizing on agricultural development through the renovation of ancient irrigation works (Godaliyadda et al. 1998). Many irrigation systems have been either rehabilitated or being rehabilitated to ensure reliable water supplies to farmlands. Deduru Oya Reservoir project is one of the several under-rehabilitation projects. Detailed description of the Deduru Oya project, the hydrology, and the inflows are described in a separate chapter of this volume. Only a brief description is provided here that is relevant to the water allocation modeling study.

Potential water resources in the basin are the direct rainfall, streamflow, surface (tanks) water storage, and groundwater storage. Quantity of water availability varies spatially and temporally across the basin, significantly. There are very low flows in the stream usually during January, February, July, and August months. Surface water resources in Deduru Oya are very much influenced by the climatic pattern and steep terrain in the upper catchment. The water available from the rainfall and collected in the existing tanks is not sufficient for two season cultivation. Seventy percent of annual rainfall in the region flows to ocean without being

Table 8.1 Details of existing and proposed irrigation area under Deduru Oya Reservoir project

Components	Irrigable area (ha)		
	Exsisting	Proposed	Total
Deduru Oya basin			
LB canal	2400	300	2700
Ridibendi Ella (D/S)	2400	600	3000
RB canal	1000	300	1300
Mee Oya basin using transbasin canal			
Iginimitiya	2640	0	2640
Radavi Bendi ela	210	400	610
Tabbowa tank	865	0	865
Total	9515	1600	11115

utilized in any way to serve needs of the local population. As a result, an optimal level of agricultural development has not been achieved.

Deduru Oya Reservoir project is aimed to exploit the Deduru Oya water resources in improving the cropping intensity of existing agricultural lands under tank irrigation systems and developing new agricultural lands in the Mee Oya and the Deduru Oya basins to enhance productivity. The project, on completion, with about 45-km-long left bank main canal, 33-km-long right bank transbasin canal, and 27-km-long branch canals will be able to irrigate over 11,115 ha (Table 8.1). The project envisages construction of a 75 MCM reservoir with two sluices and eight radial-gated spillways. The 2.4-km-long earthen dam with full supply level of 70 m above mean sea level will result inundation of 2000 ha land. Figures 8.12 and 8.13 show the water distribution arrangement of the Deduru Oya Reservoir.

8.4.2 Environmental Flow Requirement

There is an increasing awareness of the need to release a minimum amount of water along a river to ensure the continued functioning of ecological process that provides much-needed goods and services for downstream community as well as maintenance of biodiversity. Water, which is allocated and made available for maintaining ecological processes in a desirable state, is referred as the instream flow requirement, environmental flows, or environmental flow requirement. The allocation of water to satisfy environmental uses initially developed out of the need to release from dams minimum flows to ensure the survival of often a single aquatic species with high economic value. However, the provision of environmental flows that attempt to preserve natural flow characteristics such as timing, frequency, duration, and magnitude of flows is considered important for the sustenance of freshwater ecosystems, since the flow regime is one of the major drives of ecological processes on a river. The practice of environmental flow requirement began as a commitment to ensuring a "minimum flow" in the river, often fixed at 10% of mean annual runoff

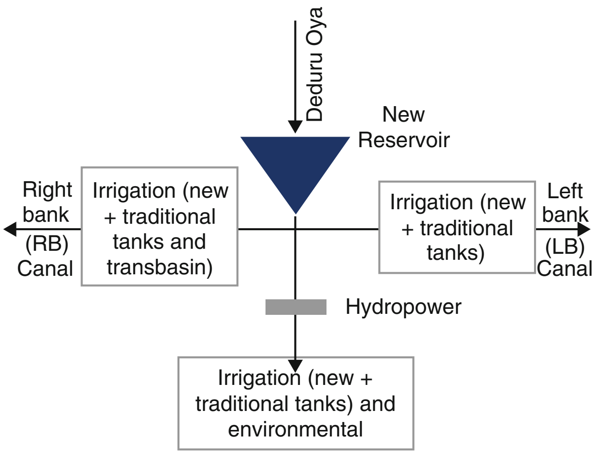


Fig. 8.12 Schematic representation of Deduru Oya Reservoir project

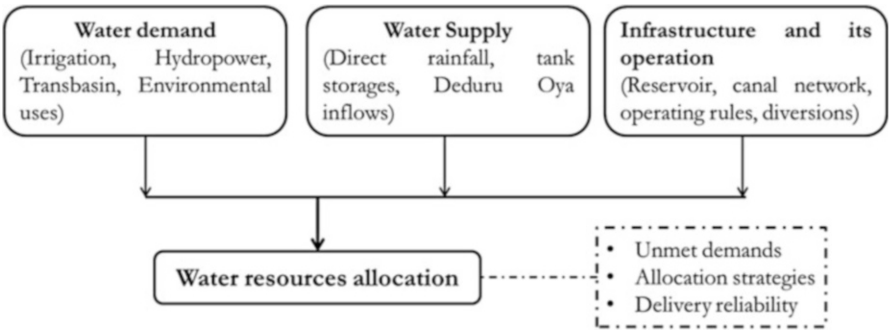


Fig. 8.13 Schematic of water supply and demand management

(World Commission on Dams 2000). In this study, a minimum of 10% normal climatic year monthly river discharge has been ensured as environmental flow requirement for testing the water supply and management scenarios.

8.4.3 Irrigation Water Requirement

Calculation of irrigation water requirement needs crop, climate, and soil datasets of the study area. Paddy (rice) is the main crop in the region accounting for most of the agricultural water demand. The climatic data includes reference evapotranspiration and rainfall. This study used the Cropwat model by FAO Land and Water Development Division for calculation of irrigation water requirement. The irrigation water requirement is defined as the difference between the crop water requirements and the effective precipitation (FAO 2000). The primary objective of irrigation is to apply water to maintain crop evapotranspiration when precipitation is insufficient.

Crop water requirement (CWR) refers to the amount of water required to compensate for the evapotranspiration loss from the cropped field. Estimation of the crop CWR is derived from crop evapotranspiration (crop water use), which is the product of the reference evapotranspiration (ETo) and the crop coefficient (Kc). The climatic data (ETo and rainfall) used for the calculations of irrigation water requirement (IWR) is based on Batalagoda station (Dharmarathna et al. 2011). Information on soil data is based on textural properties ISRIC-WISE global soil data (Batjes 2008). The soils in the area are predominantly coarse textured, ranging from loamy to sandy loam in the surface horizons and from sandy loam to clay in the subsurface horizon. Red loamy soil type was assumed for the study area after reviewing textural information and "preliminary assessment of surface water resources" by Wickramaarachchi (2004). Soil parameters are based on the standard values for red loamy soil in the Cropwat model sample datasets. Calculation of IWR at scheme level for a given year is the sum of individual CWR calculated for each irrigated crop. Multiple cropping (several cropping periods per year) is thus automatically taken into account by separately computing CWR for each cropping period. Calculation of scheme IWR has been illustrated through Tables 8.2, 8.3, 8.4, 8.5, and 8.6. Annual irrigation water requirement with system efficiency 0.5 (application efficiency 0.7 $\times$ conveyance efficacy 0.7) and 0.6 was found to be 24,354 and 20,295 cubic meter per hectare, respectively. Monthly variation of the irrigation water is shown in Fig. 8.14. Total irrigation demands in left, right, and downstream side is presented in Table 8.7.

Table 8.2 Monthly variation of rainfall and reference evapotranspiration at Batalagoda climate station

Month	Total rainfall (P), mm	Effective rainfall, (0.8*P) mm	ET_o, mm/day)
Jan	42.9	34.3	4.5
Feb	26.9	21.5	5.1
Mar	95.5	76.4	5.7
Apr	180.9	144.7	5.7
May	45.4	36.3	6.2
Jun	34.0	27.2	6.4
Jul	25.2	20.2	6.0
Aug	31.2	25.0	6.8
Sep	56.5	45.2	6.4
Oct	200.1	160.1	5.0
Nov	207.8	166.2	4.1
Dec	105.4	84.3	4.1

Table 8.3 Details on different stages of rice crop growth

Crop name: rice			Transplant date:			Harvest date:		
	Nursery	Land preparation		Growth stage				Total
Stage		Total	Puddling	Initial	Develop	Mid	Late	
Length (days)	25	20	5	20	30	30	25	130
Crop coeff, Kc (dry)	0.70	0.30		0.50	1.05		0.70	
Crop coeff, Kc (wet)	1.05	1.05		1.10	1.20		1.05	
Rooting depth (m)				0.10			0.60	
Puddling depth (m)			0.40					
Nursery area (%)	10.00							
Critical depletion	0.20			0.20		0.20	0.20	
Yield response factor				1.00	1.09	1.32	0.50	1.10
Crop height (m)						1.00		

Table 8.4 Input parameters for red loamy soil

Soil parameters	Values	Units
Total available soil moisture	180	mm/meter
Maximum rain infiltration rate	30	mm/day
Maximum rooting depth	900	Centimeters
Initial soil moisture depletion	0	%
Initial available soil moisture	180	mm/meter
Drainable porosity	10	%
Critical depletion for puddle cracking	0.6	Fraction
Maximum percolation rate after puddling	3.1	mm/day
Water availability at planting	5	mm WD
Maximum water depth	120	mm

Table 8.5 Cropping pattern for a year

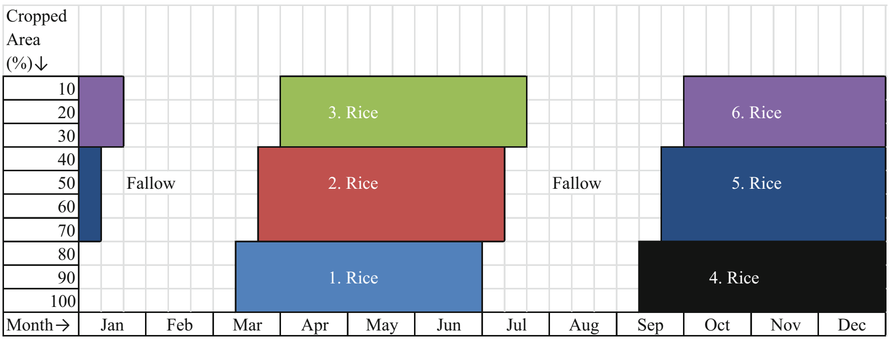


Table 8.6 Scheme irrigation water requirements

Months→	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Rice	0	65.5	261.9	57.8	206.8	178.1	0	0	0	0	0	0
2. Rice	0	0.6	275.6	50.4	204.2	207.9	41.2	0	0	0	0	0
3. Rice	0	0	174.5	96	197.3	213.3	113.2	0	0	0	0	0
4. Rice	0	0	0	0	0	0	0	78.8	311	22.7	2.2	54.9
5. Rice	19	0	0	0	0	0	0	0.8	323.6	19.1	2.2	74.8
6. Rice	62.4	0	0	0	0	0	0	0	205.8	15.5	2.2	78.2
Net scheme irr. req.												
In mm/day	0.8	0.7	7.8	2.2	6.5	6.7	1.6	0.8	9.5	0.6	0.1	2.3
In mm/month	26.3	19.9	241.2	66.3	202.9	200.6	50.4	24	284.5	19.1	2.2	69.9
In l/s/h	0.1	0.08	0.9	0.26	0.76	0.77	0.19	0.09	1.1	0.07	0.01	0.26
Irrigated area (% of total area)	70	70	100	100	100	100	70	70	100	100	100	100
Irr. req. for actual area (l/s/h)	0.14	0.12	0.9	0.26	0.76	0.77	0.27	0.13	1.1	0.07	0.01	0.26

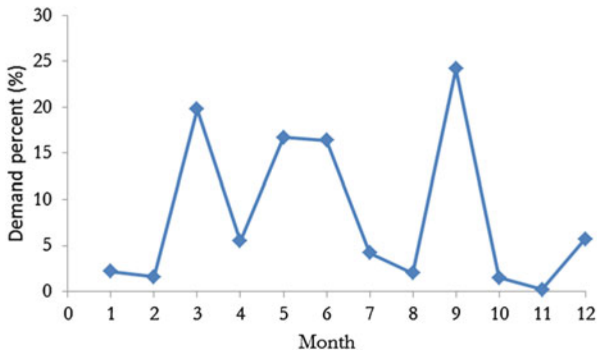


Fig. 8.14 Monthly variations of the irrigation water requirements

Table 8.7 Total irrigation water requirements in left, right, and downstream schemes

Irrigation water requirement						
Month	m3/ha	Monthly variation (%)	Left bank for 2700 ha in m3/s	Right bank for 1300 ha inside Deduru basin in m3/s	Transbasin to Mee Oya basin for 4115 ha in m3/s	Downstream for 3000 ha in m3/s
Jan	536	2.2	0.540323	0.260155	0.8234916	0.60035842
Feb	387	1.6	0.43192	0.207961	0.6582775	0.47991071
Mar	4821	19.8	4.859879	2.339942	7.4068156	5.39986559
Apr	1348	5.5	1.404167	0.67608	2.140054	1.56018519
May	4071	16.7	4.103831	1.975918	6.2545419	4.55981183
Jun	3992	16.4	4.158333	2.00216	6.337608	4.62037037
Jul	1018	4.2	1.02621	0.494101	1.5640196	1.14023297
Aug	482	2	0.485887	0.233946	0.7405279	0.53987455
Sep	5892	24.2	6.1375	2.955093	9.3540046	6.81944444
Oct	363	1.5	0.365927	0.176187	0.5577005	0.40658602
Nov	52	0.2	0.054167	0.02608	0.082554	0.06018519
Dec	1393	5.7	1.404234	0.676113	2.1401564	1.56025986

8.4.4 Inflows Estimation for Ancient Tanks

SimHyd, a conceptual rainfall-runoff model, was used to simulate daily inflows toward the left bank ancient tanks (Fig. 8.15). SimHyd model has been extensively used for various applications (Podger 2004; Chiew and Siriwardena 2005). The SimHyd model is a component of the rainfall-runoff library (RRL) produced by the Cooperative Research Centre for Catchment Hydrology, Australia. The structure of SimHyd and the algorithms describing water movement into and out of the storages are shown in Fig. 8.16. In this model, daily rainfall first fills the interception store, which is emptied each day by evaporation. The excess rainfall is then subjected to an infiltration function that determines the infiltration capacity. The excess rainfall that exceeds the infiltration capacity becomes infiltration excess runoff. Moisture

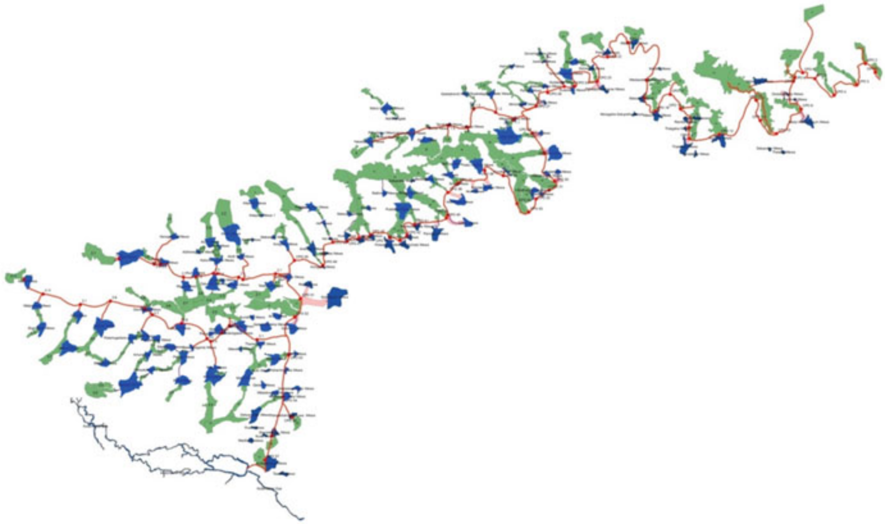


Fig. 8.15 Ancient tanks and their irrigation areas along the left bank canal network

that infiltrates is subjected to a soil moisture function, which diverts the water to the stream (interflow), groundwater store (recharge), and soil moisture store.

Calibration and validation of the rainfall-runoff model was carried out using hydroclimatic data at Tittawela tank. The Tittawela tank has drainage area of 2.95 km^2. Calibration of the model was tested over the period May 1, 1995, to December 31, 1995. The model performance is illustrated by comparing observed daily and simulated daily streamflow values over the period June 1, 1996, to March 31, 1997, as shown in Fig. 8.17. The calibrated/validated rainfall-runoff model enabled generation of daily inflows to the ancient tanks using respective drainage area and climatic data. Thiessen polygon method has been used for estimating coverage areas of different rainfall stations in left bank canal side (Fig. 8.18). The model possesses both manual as well as automatic optimization facilities for parameter calibration. In this study, SCE-UA (shuffled complex evolution University of Arizona) option was selected for carrying automatic optimization. The Nash-Sutcliffe coefficient (E) of efficiency was used as a measure of the model performance (Nash and Sutcliffe 1970). The E value describes agreement between all modeled (Q_m) and observed (Q_o) runoffs, with $E = 1.0$ indicating that all the modeled runoffs are same as the recorded runoffs (Eq. 8.1). The Nash-Sutcliffe coefficient for the calibration and validation was found as 0.93 and 0.69, respectively:

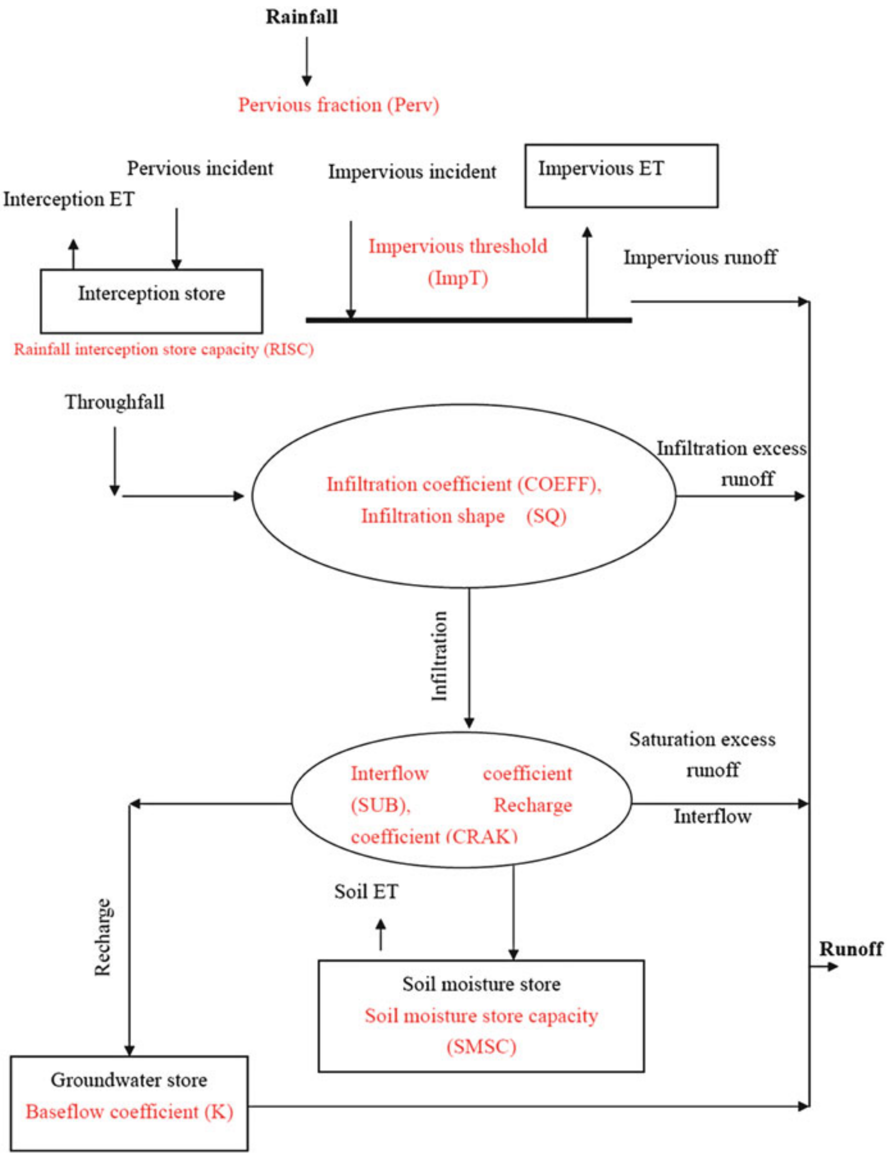


Fig. 8.16 Structure of SimHyd rainfall-runoff model

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_{\mathrm{o}}^{t} - Q_{\mathrm{m}}^{t}\right)^2}{\sum_{t=1}^{T} \left(Q_{o}^{t} - \bar{Q}_{o}\right)^2} \tag{8.1}$$

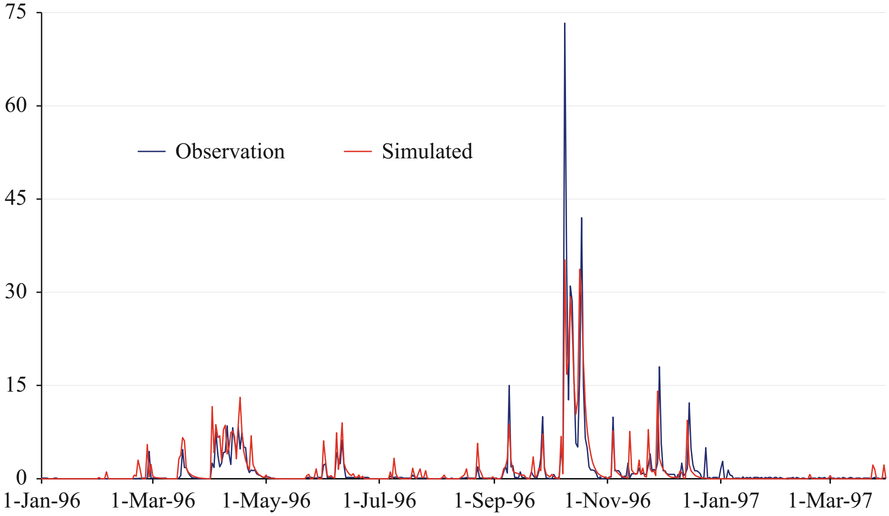


Fig. 8.17 Comparison of observation and simulation daily runoff over validation periods

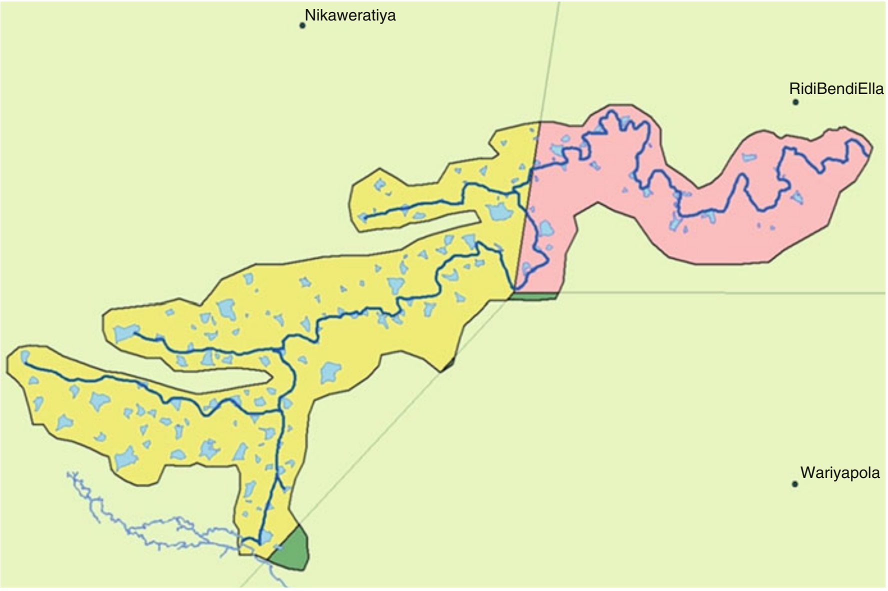


Fig. 8.18 Thiessen polygons for estimating rainfall coverage area over the LB canal region

8.4.5 *Inflow to Deduru Oya New Reservoir*

The inflow to Deduru Oya Reservoir is taken from the monthly inflow data from the feasibility study. The observed inflows show a high variability, and the normal year corresponds to the amount of flow with 50% probability. The inflow to ancient irrigation tanks connected to the LB canal is only about 2% of this normal inflow to Deduru Oya Reservoir. Therefore, the attraction of revived ancient tanks comes mainly from cultural, environmental, and societal benefits and empowerment it brings at village level. In order to understand the role the ancient tanks can play, we considered the normal year flow conditions and extreme dry weather condition flow. The dry condition is assumed to constitute of 20% (80% non-exceedance) monthly flows, and these normal and dry estimates are shown in Fig. 8.19 and Table 8.8.

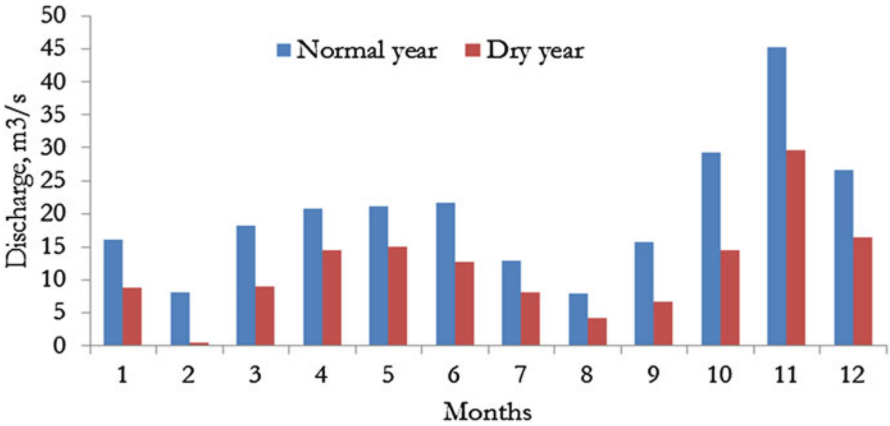


Fig. 8.19 Deduru Oya inflows to reservoir during normal and extreme dry climatic year

Table 8.8 Comparison of surplus/deficit water in normal and extreme dry climatic year

Month	Total water demand (m3/s)	River flow (m3/s)		Water surplus/deficit (m3/s)	
		Normal year	Dry year	Normal year	Dry year
January	8.62	16.1	8.9	7.48	0.28
February	8.3	8.2	0.4	−0.1	−7.9
March	21.83	18.2	9	−3.63	−12.83
April	11.22	20.7	14.5	9.48	3.28
May	19.33	21.1	15	1.77	−4.33
June	19.5	21.7	12.8	2.2	−6.7
July	10.08	13	8.2	2.92	−1.88
August	8.46	7.9	4.2	−0.56	−4.26
September	26.84	15.7	6.7	−11.14	−20.14
October	8.1	29.2	14.6	21.1	6.5
November	7.16	45.3	29.6	38.14	22.44
December	11.22	26.7	16.4	15.48	5.18

8.4.6 Water Allocation

There are several tools, which are designed to help water supply and demand management in river basins. WEAP model was selected for this study because of its robustness and ease of use for developing and testing the water supply and demand management (Hussein and Weshah 2009; Holf et al. 2007). The WEAP model is GIS-based integrated water resources management tool that integrates different water supplies and demands at catchment scale. WEAP was developed by the Stockholm Environment Institute. The WEAP model uses the basic principle of water balance accounting. WEAP represents a particular water system, with its main supply and demand nodes and the links between them, both numerically and graphically. Users specify allocation rules by assigning priorities and supply preferences for each node; these preferences are changeable, both in space and time. WEAP then employs a priority-based optimization algorithm and the concept of equity groups to allocate water in times of shortage. The simplicity of representation means that different scenarios can be quickly set up and compared and it can be operated easily. Water allocation to demand sites is done through linear programming solution. Therefore, demand site satisfaction is maximized subject to the mass balance, supply preferences, demand priority, and other constraints. Figure 8.20 shows schematic view of study area at WEAP platform.

Scenario analysis enables to answering of "what if" questions such as: what unmet demands can be expected if current trends are projected into the future? What alternative allocations could be? How should reservoirs be operated? In Sri Lanka there are two rice-growing seasons. The first is the Yala, which is the

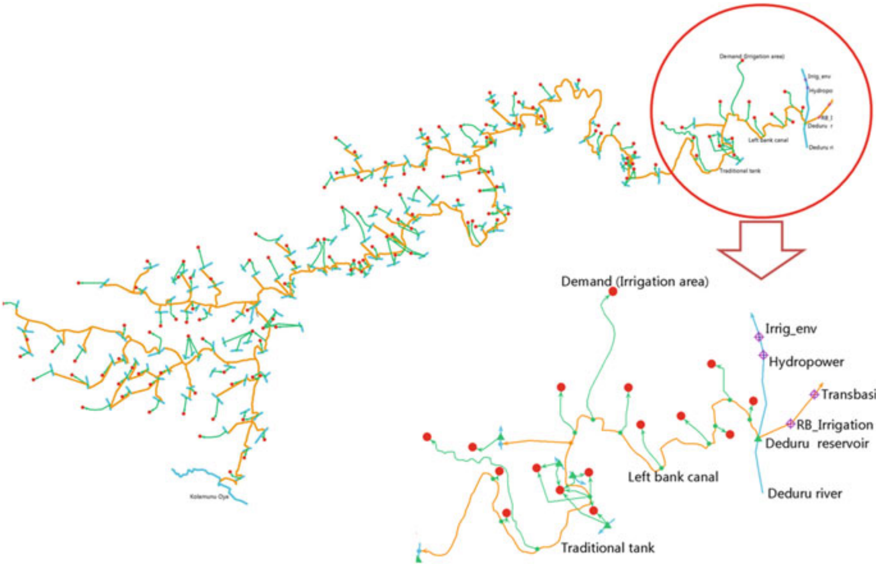


Fig. 8.20 Schematic view of Deduru Oya Reservoir project system at WEAP platform

combination of first intermonsoon rains from March to April and the southwest monsoon rains that takes place in May to September. Maha is the second growing season that starts with the arrival of second intermonsoon rains that starts in mid-September/October and continues up to late January/February with northeast monsoon. The following scenarios were created for developing and testing water supply demand management scenarios considering the two major rice cultivation seasons:

- Tanks only for two cultivation season for normal weather: The coverage and unmet water demands point out that most tank supplies alone are not able to meet the two season irrigation water requirements. Water shortages occur in the months of March, May, June, and September.
- Tanks only with single Maha season cultivation normal weather: Excluding few tanks, most of tanks are able to meet Maha season irrigation water requirements. Water shortage occurs for some of the tanks in September. However, tanks with full demand coverage are more than 75%.
- Proposed reservoir supply only for normal weather: Reservoir supply in normal climatic year is well enough to meet all the irrigation, hydropower, and environmental flow requirements.
- Proposed reservoir supply only for extreme dry weather at 20% monthly inflows: The total irrigation demand cannot be accommodated in the reservoir-only scenario. Alternative water allocations need to be considered. Water shortage occurs in the month of September.
- Tanks and reservoir with extreme dry year flows: This modeling is carried out with operation of ancient tanks and the new main reservoir freely without any constrains. This arrangement improves the performance in meeting the irrigation demand, but still there is a shortfall in September where only 90% of the demand can be met.

The coverage of the above scenarios is summarized in Fig. 8.21. In order to achieve full coverage during such extreme dry weather conditions, it is necessary to understand the performance of individual ancient reservoirs. The scenario analysis shown in Fig. 8.21 is arrived assuming ancient tanks are operated without constraints. The simulation shows that they also would fail in September. The performance of ancient tanks varies as they differ in storage volume and command area. The deficit volume in September in an extreme dry year is about 1MCM if only new reservoir is used for irrigation for the left bank. On the other hand, the total capacity of the ancient irrigation tanks that will be connected to the LB canal is around 9 MCM. Even in the extreme dry run, the inflows to the ancient system are sufficient to meet the 1 MCM deficit from main reservoir, if water is conserved for irrigation in September in the ancient tanks. The demand coverage under these scenarios is shown in Fig. 8.22. Thus, prioritizing September irrigation can help achieve 100% efficiency in an extreme dry year if the central water management by the irrigation department issuing LB canal irrigation water and the village tanks managed locally by the elected “jalapalaka” carries out water management jointly.

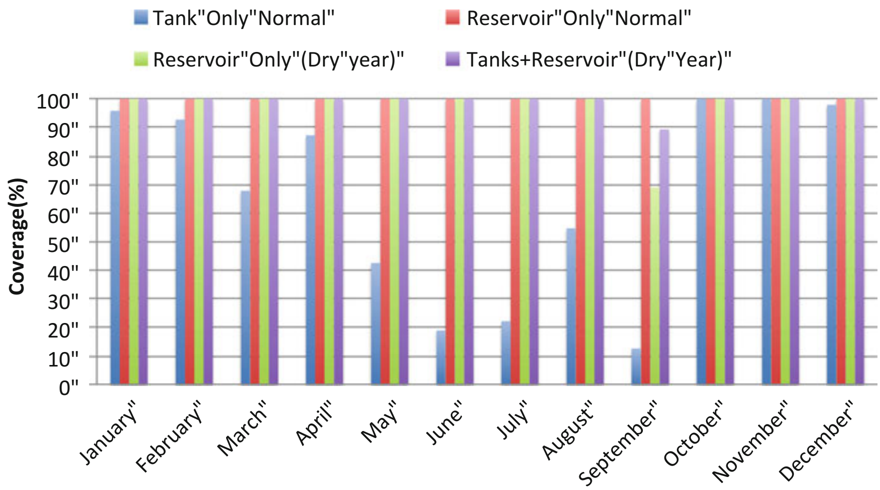


Fig. 8.21 Coverage of irrigation demand under different source combination scenarios for normal and extreme dry weather conditions

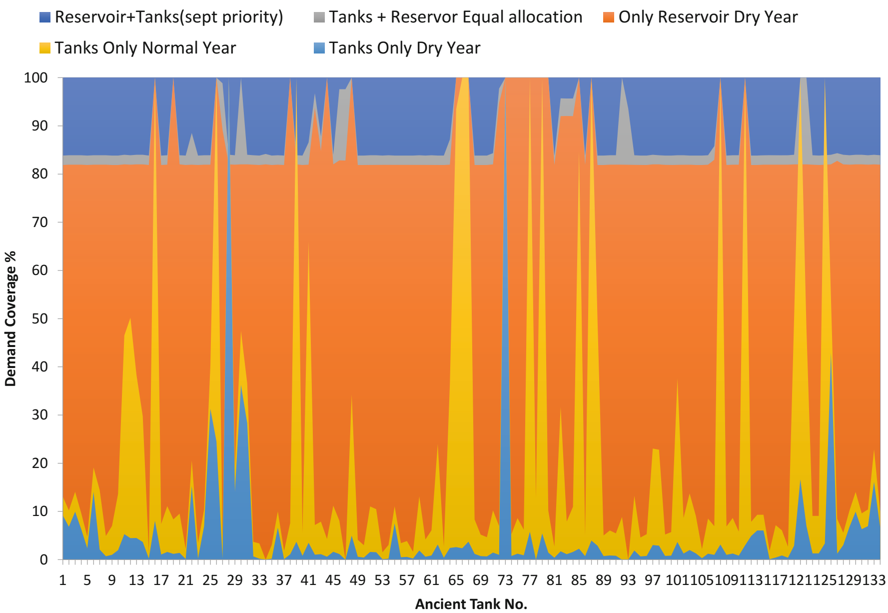


Fig. 8.22 Irrigation demand coverage under different scenarios, including joint management prioritizing meeting September demand

8.5 Water Management in Mosaic Irrigation Systems

Water management in the combined ancient and modern irrigation system requires special attention as introduced earlier due to the different types of management strategies adopted in ancient tank irrigation and modern irrigation systems. In the ancient village tanks, the farmers are responsible for allocating a finite amount of water accumulated during the rainy season among the farmers in the villages. In the modern systems, irrigation department issues water at distribution canals, and the farmers manage the water below this level through field canals. While the former operates in a system management concept, the latter in general obtain water when and needed from the free-flowing canals. However, in recent times, experimental water management in modern irrigation systems based on allocating finite water volume from the flowing canals, termed bulk water allocation (BWA), has proved to be effective and efficient. In this study, adaptation of BWA in the Deduru Oya mosaic system is investigated.

8.6 Water Management in Ancient Tanks

Traditionally water management in village tanks was carried by a manager called "Vel Vidane" who is paid with a share of rice grown by villagers (Samarasinghe and Sumanasekere 2005). This renders *Vel Vidane* accountable to all the villagers as he allocates water according to the water availability in the tanks. A unique feature of this management is a practice called "Bethma" where land near water source is reallocated temporarily to enable everybody to cultivate during season of scarcity. Farmers may grow either paddy or other crops on the land allocated. Land may be allocated proportionately to original ownership, but in general nonproportional with each landholder getting one plot as allocated by Vel Vidane. Some pressure by Vel Vidane is needed as small holders would not benefit if proportionately distributed and large holders feel unfairness if equally distributed. After the British abolished the Vel Vidane system, the water allocation is now carried out by Farmer Association (FO) or by an appointed "jalapalaka." Figure 8.23 shows the general distribution of the paddy fields where the old (core) area is the area that can be cultivated during water scarcity periods and is redistributed under Bethma system.

In recent times Bethma practice is on the decline in many areas. New agro-wells and other groundwater sources also have contributed to expansion of additional paddy fields, which makes it difficult to judge eligibility of land under Bethma. Many work around to avoid Bethma – starting second season early before a decision is taken. The reason for avoiding Bethma is due to the investments farmers have made on their fields in terms of fertilizer and weed control. In some areas those who

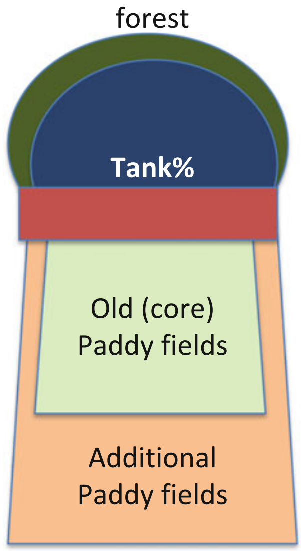


Fig. 8.23 The distribution of paddy fields under tank irrigation

could not cultivate in "Maha" season are given priority in "Yala" season. In the Deduru Oya basin, it was found that many farmers are reluctant to share land under reallocation scheme during the dry periods.

8.7 Modern Water Management Practices

Modern Participatory Irrigation Management in Sri Lanka started back in the 1980s. Before 1980, major irrigation scheme, Gal Oya, was reported to be uncooperative and experienced constant violence where the upstream was dominated by Singhalese and the downstream by Tamil. The participatory management work was anticipated to be very difficult. However, participatory management was built up successfully throughout 1980–1985 with the help of irrigation organizer (IO), external catalysts who play crucial roles in gaining farmers' trust and bridging government agency and farmers (Uphoff and Wijayaratna 2000). Farmer organization in Gal Oya has been repetitively reported as a success story, exemplified almost a decade after implementation during the 1997 dry season, where a much larger plot of land were successfully cultivated in the area due to efficient farmers' organization despite severe water scarcity (Uphoff and Wijayaratna 2000).

Subsequent failure by the government to collect irrigation fees to recover the operation and maintenance cost of irrigation systems in the country and success in Gal Oya prompted "Participatory Management Policy" 1988 to hand over operation and maintenance work to farmers themselves. Following this policy, INMAS (Integrated Management of Major Irrigation System), MANIS (The Management of Irrigation System), and Mahaweli Authority have implemented participatory approach in four major schemes in the Mahaweli basin and in 35 major schemes and 160 smaller schemes in the rest of the country (Brewer 2004).

In the year 1990, Irrigation Management Policy Support Activity (IMPSA) was established in the country to assess recent experience of participatory management and recommend suitable policies and guidelines. Through consultation of farmers and officials in Colombo, a consensus was to be achieved on what to do for the next decade (Merry et al. 1991). IMPSA secretariat went through numerous good effort and produced a series of ten very helpful Policy Papers, guiding the steps to establish farmer's organization, build capacity, and strengthen the institution in Sri Lankan context.

8.8 Bulk Water Allocation System (BWA)

The concept of "bulk water allocation" (BWA) was introduced into the area for pilot testing to find out a methodology, to be used as a broad-based solution for water management problems in major irrigation schemes (Gunaratne 2003).

The system starts from the smallest unit of field canal group, with an elected field canal leader. All field canals under one distributary canal belong to a DCFO, led by an elected leader. Leaders of 10–12 DCFOs would come together and attend monthly unit-level committee meetings, chaired by unit manager with technical officers as secretary. Unresolved problems from these meeting would then be brought to monthly block-level committee meeting, which is attended by all 38 DCFOs in the block, block-level officers (including a block engineer, officers for community development, agriculture and institutional development) and *jalapalaka*, the elected water manager. Unresolved problems from this meeting would then be brought to project-level committee meeting held once in every 2 months, chaired by resident project manager and attended by farmer representatives. With the institutional environment, problem, and conflict resolution, decision-making and information can flow transparently and systematically from lower level to upper level, and vice versa, supporting the proper functioning of the whole system. The structure of the water management system is shown in Fig. 8.24.

In a pre-cultivation season meeting, farming community get together to discuss and decide on their own cultivation plan, water issuing dates, etc. In a jointly managed system like the Mahaweli H, as farmers rely on the higher level for water allocation, a preseason meeting offers an extra step for farmers to propose what they wish to cultivate themselves, taking into consideration climatic, soil conditions, and market demand. Water demand calculation begins from the individual farmers in a field canal. The cropping pattern and required water is then aggregated at the field canal and then distributary canal and handed on to block level. The summing of requirements from all blocks constitutes the system requirement. Local officers would usually negotiate and discuss with farmer leaders to come up with a reasonable plan. The resident project manager would then send this

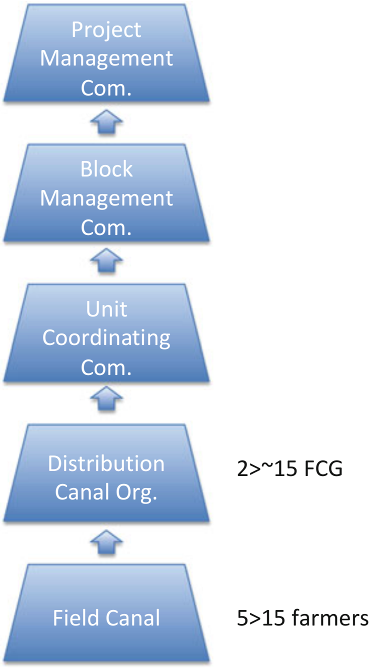


Fig. 8.24 Management structure of system H in implementing BWA

requirement to the Water Management Secretariat (WMS)[1] to request for diversion of water to system H for the season (Gunawarden and Wickramaratne 2011). If the amount of water requested is available, the demanded bulk water would be granted. If not, cultivation plan would be adjusted and finalized in cultivation season meeting, together with water issue dates and other details. The system attempts to simulate a water-storing tank, where a fixed amount of water is available for farmers in the beginning of a season. Like a bank account, any withdrawal or deposit would directly affect future availability of water. Engineers are responsible of updating the balance. Farmers learn to manage water with these virtual figures as guidance.

[1]The management of the water resources of the Mahaweli Project is entrusted to the Water Management Panel (WMP) which is headed by the director general of MASL and consists of all heads of government agencies concerned with the management and operation of the Mahaweli Project. The director of Water Management Secretariat (WMS) functions as the secretary of both the Policy Planning Panel and the Mahaweli Water Management Panel, and this helps to maintain the necessary communication link between the two panels. The WMP is also responsible for the overall cultivation programs in the areas served by the Mahaweli Project. The WMP is assisted in its works by a technically specialized Water Management Secretariat (WMS) constituted within the MASL. It is responsible for the operational planning and coordination responsibilities of the WMS extend to the other operating agencies as well. The WMS provides information and recommendations to the WMP to assist it in reaching its operational policy decisions. Once the decisions are made, the monitoring of the total program is directed by the WMS.

Jalapalaka or water master plays a crucial role in the operation of water distribution. Their duties include issuing water according to timetable, keep recording of water account from reading of calibration chart and gauges, collecting rainfall data, reporting on crop progress, and arising issues. There are two types of *jalapalaka*, those in charge of distributary canals, selected and paid by their respective DCFOs, and those in charge of main canals and branch canal, selected in block-level committee meeting but paid by the government. A high level of cooperation and coordination between these two types of *jalapalaka* is required to ensure smooth water issuing, as water can also be released into distributary canals on time if it is released in the main canal or branch canals on time in the first place. They usually undergo intensive training, mostly by the irrigation engineer. DCFOs rely heavily on their *jalapalaka* for water distribution and coordination with block-level officers.

Performance of water supply after introduction of BWA has increased considerably in terms of gross water quota allocated at the block levels and the main canal level for both seasons. The extent cultivated during dry season has increased 52%, with an increase of annual cropping intensity by 10.7%. In the past, farmers adopted "Bethma" system in water scarce seasons, which ceased after the implementation of the BWA system. After the initiation of BWA, 45% of farmers have changed their cropping pattern by introducing new low water consumptive and high-value cash crops. The majority of such farmers are in the tail end areas, accounting for 60% of total farmers. Crop diversification has been one of the main activities undertaken by the MASL (Aheeyar 2007).

BWA, which emulates a tank, is the ideal system to be adopted in the new Deduru Oya project where water management has to be closely coordinated between the modern reservoir and the ancient tanks.

8.9 Implementing BWA in Deduru Oya Basin

With the completion of Deduru Oya Reservoir project, there is a necessity to implement a new water management system, as the irrigation from canals is completely different from tank irrigation. In order to understand the requirements of new farmer organizations (FO) after the completion of the Deduru Oya basin, an extended field study was carried out organizing discussions with four FOs in four villages, interviewing 16 farmers, and holding discussions with field-level officers who are Agriculture Research and Production Assistants overseeing the minor irrigation schemes. Major issues identified are summarized below that can be taken into consideration when new management structures are implemented.

Unlike from a tank, it is impossible to visualize the total amount of water that would flow through the canal to the field. It is thus difficult to divide water equally. Water source is relatively unsecure compared to tank water, and water issue dates are inflexible. Farmers need to learn to irrigate in a limited time period. Overall, a more sophisticated management system than the current one is required. The jalapalaka committee and their decision-making cater to the physical structures of the village while addressing equity and efficiency simultaneously. To improve water use efficiency, a quantitative understanding of water use needs to be instilled among farmers. Measuring device should be provided in tank and turnout to measure the water use each time. Farmers should acquire the knowledge to calculate and understand whether they are conserving or wasting water. Further training can be provided on best practices to conserve water and prevent wastage.

Rehabilitation of irrigation structures, e.g., gates for turnouts, is also to be carried out as soon as possible with external financial and technical assistance to enable proper water management to take place. There is a lack of financial capacity, technical, and management knowledge regarding irrigation system. Intensive training about maintenance of canals and water management should be provided to all farmers if possible. Awareness programs must be held simultaneously. Awareness programs also strive to correct the attitude of farmers, regarding attending meetings, voicing up of opinions, and compliance and enforcement of rules.

At present, when water level in the tank is low, water would not be withdrawn for cultivation but reserved for animals and domestic usage. Farmer leader is well aware about issues of environment and sustainability. These awareness and values are valuable and should be maintained in the future, while production-orientated mindset is best to be avoided. However, it is also recognized the need of awareness program to correct some of the farmers' attitude, especially rule breakers.

8.10 Conclusions

The new Deduru Oya Reservoir will provide water resources many folds over the current existing ancient irrigation tanks in the left bank canal side of the Deduru Oya area. The main focus therefore would be to provide the social and cultural cohesion, harmony with nature, and resilience in extreme events utilizing the ancient irrigation network. The enhanced water resources provide opportunities to improve livelihoods of the farmers in the region. Thus, a holistic approach toward empowering the farmer communities through integrated water management practices is necessary to make full use of the Deduru Oya irrigation project.

The analyses of inflows to both new and ancient irrigation systems show that the reservoir alone will have around 15–20 times the water resources available compared to the ancient systems and is capable of supporting year-round irrigation and additional coverage for rice farming. However, the ancient irrigation systems can play a major role in providing the resilience to the system to absorb shocks from an extreme dry climatic year. With the enhanced inflows from the modern reservoir, they will be able to provide water for year-round cultivation of existing farmlands and also provide opportunities to grow other food crops to enhance income.

The challenge facing the system is the design of an appropriate water allocation system and implementing a robust water management system. The WEAP model employed showed feasible water allocation scenarios and can be used to construct appropriate operation rule curves for the reservoir, combining with the demands of right-hand canal, which was taken into to analysis but not discussed in detail here. In addition, the various inlet structures, such as level crossings and cascade supplement, can be individually accounted for in the detailed water allocation model constructed for the combined new and ancient irrigation systems.

For water management, the bulk water allocation (BWA) model adopted in system H of the Mahaweli basin was studied and found to be a promising model to be used in the Deduru Oya basin project. The assessment of implementing BWA through a detailed survey of the Deduru Oya basin has been carried out and showed a positive attitude by the farmer community. In implementing the BWA, it is important to establish (a) clear and measurable water entitlement; incorporate (b) "risk management" in comprehensive capacity building that includes social, technical, and financial aspects; and provide (c) transparency in decision-making and appropriate power sharing.

The Deduru Oya project provides a unique opportunity to combine the efficient large-scale modern systems with resilient localized ancient systems promoting socio-economic development in harmony with nature through building mosaic systems. These mosaics should cover both physical (structural mosaics) and social (management mosaics) aspects. Further analysis on economic aspects, in linking micro production with macroeconomy through crop and livelihood diversification, should be studied in the future.

References

Aheeyar, M.M.M. (2007). Experiences of bulk water allocation in large scale irrigation management. A Paper presented at The 4th Asian Regional Conference & 10th International Seminar on Participatory Irrigation Management in Tehran, Iran. Retrieved 16th June, 2012 from http://www.irncid.org/GetFileArticles.aspx?FilePrm¼46555_52522.pdf

Avsadahamy UB (2003) Wewa, Siri printers, ISBN-955-96820-0-8

Batjes NH (2008) ISRIC-WISE Harmonic Global Soil profile dataset (version 3.1), Report 2008/02, ISRIC-World Soil Information. http://www.sciencej.com/adenira_1_4_2010_119_125.pdf

Brewer, J.D. (2004). Present Status of Participatory Irrigation Management in Sri Lanka. INPIM. Accessed at http://www.inpim.org/leftlinks/Newsletters/N4/n4a1/view.htm

Brohier RL (1934) Ancient irrigation works of Ceylon, vol 1, 2 and 3. Ceylon Government Press, Colombo

Brohier RL (1937a) Inter-relation of groups of ancient reservoirs and channels in Ceylon. J R Asiat Soc, Ceylon Branch 34(90):64–85

Brohier RL (1937b) Interconnected large reservoirs and channels in ancient Rajarata. J R Asiat Soc, Ceylon Branch 34(90):64–85

Chiew FHS, Siriwardena L (2005) Estimation of SimHyd parameter values for application in ungauged catchments. http://www.mssanz.org.au/modsim05/papers/chiew_2.pdf

Dharmarathna WRSS, Weerakoon SB, Herath S, Rathnayake UR, Weerakoon WMW (2011) Application of Decision Support System for Agrotechnology Transfer (DSSAT) model to optimize irrigated paddy cultivation under changing hydro-climate, Technical papers, Annual Transactions of IESL, volume I, part B, pp 207–211

FAO (2000) Riceinfo, crop and Grassland Commission of International Rice Commission. Food and Agriculture Organization of the United Nations

Godaliyadda GGA, Mullegamgoda KRPM, Alahakoon AMUB (1998) Some experiences on modernization efforts in irrigation system rehabilitation in Sri Lanka. In: Proceedings of the fifth international IT IS networking meeting, Aurangabad, India, pp 151–156

Goldsmith E, Hildyard N (1984) Chapter: 24 the social and environmental effects of large dams: volume 1. In: Overview. Wadebridge Ecological Center, Cornwall

Gunaratne B (2003) Bulk water allocation concept for improving water productivity- a pilot study in Mahaweli system H. In: De Silva RP (ed) Water resources research in Sri Lanka. University of Peradeniya, Peradeniya

Gunawarden ERN, Wickramaratne KN (2011) Compendium on IWRM: module 8.4. Restraining conflicts through institutional interventions: The case of Mahaweli, Sri Lanka. Retrieved 6th May, 2012 from http://www.saciwaters.org/CB/iwrm/Lecture%20Notes/8.5.%20Operationalizing%20IWRM%20through%20River%20Basin%20Planning%20and%20Management_Gunawardena%20ERN.pdf

Herath S (2011) Framework for resilience building in traditional production systems, CECAR-ASIA inception workshop, Viet Nam National University, Hanoi, July, 2011

Holf H, Noel S, Droogers P (2007) Water use and demand in the Tana Basin – analysis using the Water Evaluation and Planning (WEAP) tool. Green water credits report 4, ISRIC – World Soil Information, Wageningen

Hussein I, Weshah RA (2009) Optimizing the water allocation system at Jordan Valley through adopting water evaluation and planning system model. Thirteenth international water technology conference, Hurghada, Egypt, pp 753–777

Leach EA (1959) Hydraulic society in Ceylon. Past Present 15:2–26

Levers RW (1890) Irrigation, Chapter 11 of Manual of the North Central Province, pp 132–169

Madduma Bandara CM (1994) Tank cascades in Sri Lanka. In: Asharul Haq K (ed) Proceedings of IRMU seminar series. Irrigation Research and Management Unit/Irrigation Department Sri Lanka, Colombo

Mendis, D. L. O. (1986). Evolution and development of irrigation eco-systems in ancient Sri Lanka. Transactions of the Institute of Engineers SriLanka 1:13–29

Merry DJ, Silva NGR, Sakhtivatel R (1991) A participatory approach to building consensus: the relevance of irrigation management policy support activity of Sri Lanka to other countries. International Water Management Institute, Colombo, Sri Lanka. Retrieved 25th April, 2012 from http://publications.iwmi.org/pdf/H010393.pdf

Nash JE, Sutcliffe JV (1970) River forecasting using conceptual models, part 1, a discussion of principles. J Hydrol 10:282–290

Panabokke CR (1999) The small tank cascade systems of the Rajarata: their setting, distribution patterns, and hydrography. Mahaweli Authority of Sri Lanka, Colombo

Panabokke CR, Sakthivadivel R, Weerasinghe AD (2002) Evolution, present status and issues concerning small tank systems in Sri Lanka. International Water Management Institute, Colombo

Parker H (1909) Ancient Ceylon, London-Luzca & Co., Published by the India Office

Podger G (2004) Rainfall runoff library, CRC for Catchment Hydrology, Australia. http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit

Sakthivadivel, R., Fernando, N., Pannabokke, C.R. and Wijayaratna, C.M. (1996). Nature of small tank cascade systems and frame work for rehabilitation of tanks within them (IIMI country paper 13). Colombo, Sri Lanka: International Irrigation Management Institute.

Sakthivadivel R, Fernando N, Brewer JD (1997) Rehabilitation planning for small tanks in cascades: a methodology based on rapid assessment, Report 13. International Irrigation Management Institute, Colombo

Samarasinghe, S.A.P. and Sumanasekere, D.U. (2005). Community empowerment and management experiences in the water sector. In Proceedings of consultation on river basin management (pp. 31–42). Lanka Jalani. Colombo, Sri Lanka: International Irrigation Management Institute.

Uphoff N, Wijayaratna CM (2000) Demonstrated benefits from social capital: the productivity of farmer organizations in Gal Oya, Sri Lanka. World Dev 28(11):1875–1890. https://doi.org/10.1016/S0305-750X(00)00063-2

Wickramaarachchi TN (2004): Preliminary assessment of surface water resources- a study from Deduru Oya Basin of Sri Lanka, APHW Proceedings. http://rwes.dpri.kyoto-u.ac.jp/~tanaka/APHW/APHW2004/proceedings/OHS/56-OHS-A341/56-OHS-A341.pdf

World Commission on Dams (2000) Dams and development: a new framework for development. Earthscan Publications Ltd, London/Sterling

Chapter 9
Conclusion: Synthesis, Recommendations, and Future Directions

Kazuhiko Takeuchi, Osamu Saito, Hirotaka Matsuda, and Geetha Mohan

Abstract This chapter summarizes 3 years of widespread research conducted under Climate and Ecosystems Change Adaptation Research in Asia (CECAR-Asia). The main aim of this study was to build agroecological bioproduction systems that adapt to climate change and to propose measures to enhance the resilience of rural production systems in three countries in rural Asia. A mosaic system was proposed to sustain these systems such that a fusion of traditional and modern systems results in a more resilient Asia now and into the future. Some of the key findings suggest that an integration of efficient large-scale modern systems with resilient localized ancient systems is a key intervention and a unique opportunity to promote a harmonious relationship with nature, whereas, extension services, timely information, and knowledge sharing are highly relevant for communities, especially those in rural areas.

Keywords Climate risks · Food production systems · Adaptive capacity · Water management · Synthesis · Future directions

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K. Takeuchi et al. (eds.), *Resilient Asia*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56597-0_9

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9.1 Conclusions

9.1.1 Resilience, Climate Risks, and Sustainable Food Production Systems

Chapters 2, 3, and 4 reveal that the impact of climate change on agricultural production is one of the main challenges in the twenty-first century. The effect of extreme weather events and climate risks on rice yields is highlighted in Chap. 2. For example, extreme weather such as heavy storms can increase threats of seawater intrusion and leakage of saltwater through dykes, thereby creating the threat of seawater intrusion into paddy fields. This may cause to mislay appropriate management practices and result in declining yields in the northern region of Vietnam. Furthermore, if the salinity levels increase in the future owing to sea level rise, crops may transform from rice to aquaculture or to other crops that are more adapted to saline conditions. Such a strategy would allow continuing economically viable agriculture in the region. This strategy also contributes toward achieving higher resilience to long-term environmental modifications due to climate change (FAO 2001; IPCC 2013). Such combined efforts through effective strategies adopted by the government, irrigation department, and farmers could cope with the threats of seawater intrusion and enhance the resilience of rice production in the Red River Delta. If unexpected events such as climate hazards or fluctuations in the price of agricultural products occur, in some cases, a partnership between rural and urban/global communities is beneficial for rural development and an increase in resilience. Resilience can be improved by adapting effective mitigation policies to climate change, hydrological management of rivers, agricultural water management, and farm-level mitigation and adaptation measures. The most recent plan is the New Rural Development (NRD) program, which is based on a certificate system similar to good agricultural practice (GAP). NRD will facilitate and support the adoption of cultivation methods with a higher awareness of environment conservation, less input, and higher utilization efficiency of agrochemicals.

The risk of climate change on agricultural production prevails; moreover, the consequences of such change for livestock are no less serious (Campbell et al. 2016; Creighton et al. 2015; Herrero et al. 2015). As described in Chap. 3, farmers who favor making a profit from their agricultural products with a preference for high risk raise larger livestock, such as cows and pigs. It should be noted that it is more difficult to raise larger livestock considering the perspective of the technology required. Therefore, farmers who follow a high-risk business strategy tend to introduce large livestock mainly to generate profit as well as in response to market demand. The second reason involves unexpected weather events, which can lead to the instability of the traditional Vuon-Ao-Choung (VAC) system, which is popular in this region. Raising livestock is therefore one of the key strategies to enhance the resilience of the income of a household. However, although raising livestock may improve the resilience at the level of individual households both generally and specifically, it may result in other unexpected problems, e.g., new environmental degradation. An efficient strategy is needed to cope against climate variability and climate-related disasters such as typhoon, floods, and saltwater intrusion; the frequency of such disasters has increased in recent years in Da Nang City, Vietnam (see Chap. 4). According to future climate change stimuli, this city must incorporate planning and developing policies relating to effective responses to climate change based on assessment of risk, vulnerability, and adaptive capacity to climate change.

9.1.2 Adaptive Capacity and Agroecological Systems

Adaptive capacity is a measure of how people respond to climate change and how they minimize the effects of change (Adger and Vincent 2005; Cohen et al. 2016). Chapter 5 highlights the fact that most farmers have a sparse knowledge of global warming and climate change. It is therefore necessary to educate farmers in the area of climate change and its impacts. Studies have shown that intensifying integrated livestock farming systems is one of the best adaptation strategies to cope with climate change and ensure the sustainability of farming and rural livelihood. In terms of household food management, a well-organized storage of farm produce and an appropriate combination of staple foods are effective strategies to deal with climate change. Development of small-scale irrigation projects such as dykes, particularly in the upland areas, will prevent the decline in crop yields and crop failures and is therefore considered the best adaptation strategy for climate change. Coupled with this, diversity and multifunctional homegarden systems play an important role in providing “general resilience” against climate and ecosystem changes. Several studies have assessed ecological and economic values in different parts of the world (Kumar and Nair 2004). These studies have shown that homegarden systems provide many opportunities for people living in rural areas in terms of income and conservation of traditional culture, biodiversity, and agrodiversity. Interestingly, traditional homegardens still exist even after recent socioeconomic changes, and they maintain high ecosystem diversity and provide a bundle of ecosystem services (see Chap. 6). However, one of the core challenges is the integration of traditional homegardens with modern technology and the global economy to enhance the resilience of the system. Moreover, it has also been shown that enhancing homegarden systems and helping them adapt to particular environmental or socioeconomic changes increase their resilience.

9.1.3 Mosaic Systems and Development of Irrigation Water Management

Mosaic systems have the potential to offer more resilience to climate, ecosystem, and socioeconomic changes. Both traditional and modern systems are used in rural

Asian communities that experience monsoons. It may be possible to enhance resilience by combining them and implementing intervention options by constructing mosaic systems that integrate traditional knowledge and modern technologies. As reported by recent studies, the importance of traditional knowledge and technology is recognized by various international initiatives, such as the Convention on Biological Diversity (CBD), United Nations Framework Convention on Climate Change (UNFCCC), and Globally Important Agricultural Heritage Systems: Food and Agriculture Organization (GIAHS: FAO). These initiatives noted that traditional technology and practice have evolved in many parts of the world and that such farming systems have overcome rigorous local environmental and historical climate changes (Koohafkan and Altieri 2011). Chapters 7 and 8 illustrate the importance of mosaic systems in the support and development of irrigation water management under a changing climate in the left bank canal irrigation development area of the Deduru Oya Project in Sri Lanka. Here, the main focus is to provide social and cultural cohesion and build a harmonious relationship with nature and resilience to extreme events using ancient irrigation networks. Enhanced water resources provide opportunities to improve the livelihoods of farmers in the region. Therefore, a holistic approach toward empowering farming communities through integrated water management practices is necessary to make optimal use of the irrigation project. Ancient irrigation systems can play a major role by adding resilience to the system and allowing it to absorb shock, such as that from an extremely dry year. These ancient systems integrated with enhanced inflows from modern reservoirs will be able to provide water for year-round cultivation of existing farmlands and provide opportunities to grow food crops to enhance income. In some hydrological models that include the contributions of both new and ancient irrigation systems, it has been shown that reservoirs alone will have around 15–20 times the water resources available when compared with ancient systems. These reservoirs are therefore capable of supporting year-round irrigation and additional coverage for rice farming.

Importantly, the effects of floods, long dry seasons, pest damage, changing rainfall patterns, forest certification systems, and market adaptation are key components to be considered. Thus, some interventions are vital to further strengthen and create a system more resilient to climate, ecosystem, and socioeconomic changes. A framework was developed for assessing and analyzing resilience in detail, and concrete strategies to enhance resilience were formulated in accordance with case studies (Table 9.1). Predominantly, the resilience rating has been assessed through a participatory and inclusive multi-stakeholder process in the respective study communities. However, across field surveys and statistical analysis, it is possible to develop strategies to cope with climate and ecosystem changes by employing traditional methods in combination with modern technologies. A resilience assessment clearly suggests that a mosaic system combining both modern and traditional systems can help realize more resilient societies.

Table 9.1 Assessment of resilience based on field surveys in Vietnam, Sri Lanka, and Indonesia

Survey location	Climate-ecosystem/ socioeconomic change	Systems	Shock resistance	Resilience rating (Current)			Intervention options	Resilience rating (after intervention)	
Homegarden	Flooding/long dry season/rainfall pattern change/pest damage/ saltwater/infiltration Market adaptation/ market economy penetration	VAC/ Pekarangan/ Kandyan/ homegarden	Cash crops, commercial livestock production, food self-sufficiency	Ecological	H	↘	Use certification system Form communities Enhance material cycling by mixed production Strengthen safety net	Ecological	H
Vietnam Indonesia Sri Lanka				Socioeconomic	L	↗		Socioeconomic	M
Vietnam Xuan Thuy	Rainstorm/flooding Disease-pest damage Saltwater infiltration International market adaptation Market economy penetration	VAC	Commercial livestock production	Ecological	M	↘	Use certification system More stable operation by combining VAC and rice farming Combine traditional and modern varieties Improve quality	Ecological	M
				Socioeconomic	M	↗		Socioeconomic	H
		Rice cultivation	Moving irrigation water source upstream Selection of varieties	Ecological	L	↘		Ecological	M
				Socioeconomic	M	↘		Socioeconomic	M

(continued)

Table 9.1 (continued)

Survey location	Climate-ecosystem/socioeconomic change	Systems	Shock resistance	Resilience rating (Current)			Intervention options	Resilience rating (after intervention)	
Indonesia Gunung Kidul	Long dry season Lack of rain/change in rainfall pattern Flooding International market adaptation Market economy penetration	Social forestry/Pekarangan	Diversity livelihood Biodiversity	Ecological	H	→	Use forest certification system Create resource management system Move to agroforestry by commercial reforestation	Ecological	M
				Socioeconomic	L	→		Socioeconomic	M
		Commercial reforestation	Sale of high value-added wood products	Ecological	L	→		Ecological	M
				Socioeconomic	H	→		Socioeconomic	H
Sri Lanka Kilinochchi Deduru Oya Mahaweli H	Dryness/declining rainfall Damage to irrigation infrastructure due to civil war International market adaptation Market economy penetration	Traditional storage water tanks	Restore/use traditional irrigation systems Multi-functionality	Ecological	M	→	Integrate new and old irrigation systems Create communities Appropriate resource management system to avoid drought	Ecological	H
				Socioeconomic	L	↘		Socioeconomic	H
		New irrigation system	Efficient use Collaborative management	Ecological	L	→		Ecological	H
				Socioeconomic	L	→		Socioeconomic	H

Authors' calculations and part of the CECAR-ASIA project output adapted from Takeuchi et al. (2016)
Note: H, L, and M indicate high, low, and medium, respectively

9.2 Recommendations and Future Directions

The principal aim of this study was to build agroecological bioproduction systems that adapt to climate change. A mosaic system was proposed to sustain these systems such that a fusion of traditional and modern systems results in a more resilient Asia now and into the future:

- It is crucial for a government that they invest in and provide effective and timely early warning systems in the most vulnerable and dangerous areas in order to protect the diversification of the natural environment, including natural ecosystems and areas resilient to disasters and climate change. Moreover, extension services and timely information and knowledge sharing are highly relevant for communities, especially those in rural areas. Such communities are often highly vulnerable to climate change and socioeconomic and political instability.
- Livelihood diversification, wherein a combination of additional strategies results in sustainable resilient societies, can be an effective strategy in rural areas. For example, the development of food diversification programs would help reduce the dependency on a single agricultural commodity, particularly when coping with weather anomalies due to climate change. Consequently, the introduction of new schemes including finance or other forms of programs is an important support that can be provided by the government.
- For local farmers to increase their social and economic status, the development of local market and appropriate natural resource management is important. Furthermore, it is necessary for the government to protect the diversity of the natural environment, including natural ecosystems and areas resilient to climate change.
- In terms of irrigation-water management, integration of efficient large-scale modern systems with resilient localized ancient systems is a key intervention and a unique opportunity to promote a harmonious relationship with nature. Conversely, the implementation of appropriate management systems would support and secure irrigation resources and avoid drought.

Based on the observations made for VAC systems, rice crops of Vietnam and Indonesia, and traditional tanks and new reservoirs of Sri Lanka, it is concluded the development of resilience-enhancing measures that depend on ecosystem services and differ from conventional technological solutions is possible. This can be accomplished through the use of mosaic systems that integrate both traditional and modern elements. In the future, a more detailed analysis of these mosaic systems must consider both the physical (structural mosaics) and social (management mosaics) aspects. These mosaic systems play an essential role to implement ecosystem-based approaches to climate change adaptation and disaster risk reduction which have been widely recognized as an important science-policy agenda (Lo 2016). Moreover, the approaches should extend to examine the economic aspects and climate risks involved in linking microproduction with the macroeconomy through agroecological and livelihood diversification.

References

Adger N, Vincent K (2005) Uncertainty in adaptive capacity. Compt Rendus Geosci 337:399–410

Campbell BM, Vermeulen SJ, Aggarwal PK, Corner-Dolloff C, Girvetz E, Loboguerrero AM, Ramirez-Villegas J, Rosenstock T, Sebastian L, Thornton PK, Wollenberg E (2016) Reducing risks to food security from climate change. Glob Food Sec 11(2016):34–43. https://doi.org/10.1016/j.gfs.2016.06.002

Cohen PJ, Lawless S, Dyer M, Dyer M, Morgan M, Saeni E, Teioli H, Kantor P (2016) Understanding adaptive capacity and capacity to innovate in social–ecological systems: applying a gender lens. Ambio 45(Suppl 3):309–321. https://doi.org/10.1007/s13280-016-0831-4

Creighton, C., Hobday, A.J., Lockwood, M., Pecl, G.T., 2015. Adapting Management of Marine Environments to a changing climate: a checklist to guide reform and assess progress. Ecosystems, 1–33. http://dx.doi.org/10.1007/s10021-015-9925-2

Food and Agriculture Organization of the United Nations (FAO) (2001) Integrated agriculture-aquaculture: a primer FAO fisheries technical paper T407, FAO, Rome, p 149

Herrero, M., Wirsenius, S., Henderson, B., Rigolot, C., Thornton, P.K., Havlik, P., de Boer, I., Gerber, P., 2015. Livestock and the environment: what have we learned in the past decade? Annu Rev Environ Resour 40, 177–202. http://dx.doi.org/ 10.1146/annurev-environ-031113-093503

IPCC (Intergovernmental Panel on Climate Change) (2013) The physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds). Cambridge University Press, Cambridge, p 1533

Koohafkan P, Altieri MA (2011) Globally important agricultural heritage systems: a legacy for the future. Food and Agriculture Organization of the United Nations, Rome

Kumar BM, Nair PKR (2004) The enigma of tropical homegardens. Agrofor Syst 61:135–152

Lo V (2016) Synthesis report on experiences with ecosystem-based approaches to climate change adaptation and disaster risk reduction. Technical Series No.85. Secretariat of the Convention on Biological Diversity, Montreal, 106 pages

Takeuchi K, Matsuda H, Saito S, Herath S, Naito D, Mohan G (2016) Building resilience in rural Asia: combining traditional and modern bioproduction systems, the challenges of agro-environmental research in monsoon Asia, NIAES series no.6, pp 13–25