Water Resources Development and Management

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Assessing Global Water Megatrends

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Water Resources Development and Management

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Foreword

'Water is life's matter and matrix, mother and medium. There is no life without water', so said Albert Szent-Gyorgyi, a Hungarian Nobel Prize winner for Medicine.

Indeed, water is life and therefore any assessment of global water megatrends is necessarily an examination of the trajectory of human development. Professor Asit Biswas, Dr Cecilia Tortajada and Dr Philippe Rohner have combined their unique expertise in putting together this volume that captures and weaves together important concepts such as the current population growth patterns and how they will impact water, the issue of sustainability in urban water management, the role of technology in addressing water management issues and the convolutions of the water-energy-food nexus. In order to address all these challenges, the authors make strong arguments for why fundamental changes in water management are necessary.

The issue of water and the global megatrends impacting all of us are areas close to the heart of Singapore. Singapore is at the vanguard of water management, driven by necessity and whose evolution mirrors the global water megatrends. From a starting point of near zero natural water resources, the island-nation has built for itself a diversified 'Four National Taps' water resource portfolio. Indeed, without the confidence that Singapore's water supply is always clean, safe and reliable, we would not have attracted investments into Singapore nor prospered.

Operationally, the National Water Agency of Singapore, PUB, is faced with the challenge of ensuring the sustainability of its closed water loop while at the same time meeting growing water demand from our industry and population. In tackling these challenges, PUB has invested heavily in research and development as well as supported the test-bedding and implementation of many new technologies in areas such as desalination and reuse, watershed management, wastewater treatment for resource recovery and industrial water technologies. Moving forward, PUB will be exploring co-location synergies between power generation and desalination, and also food waste and sludge co-digestion. In doing so, Singapore will once again be demonstrating its willingness to embrace new approaches and transform scarcity into opportunity.

This book is also seminal in drawing together perspectives from a geographically diverse list of renowned international contributors and truly reflects the universal nature of the challenge we face. May it serve as a call to action for us all!

Singapore
August 2017

Masagos Zulkifli
Minister for the Environment and Water Resources,
Government of Singapore

Preface

John F. Kennedy once said: ‘Change is the law of life. And those who look only the past or present are certain to miss the future’. He also said: ‘Anyone who can solve the problem of water will be worthy of two Nobel Prizes—one for peace and one for science’.

More than half a century after President Kennedy’s death, the above two statements appear to be more prophetic than ever, especially for the water sector. The water profession has been claiming for at least the past 40 years that business as usual can no longer be an option but behaving consistently that as if there are no feasible business unusual solutions. It is still trying to solve tomorrow’s water problems with yesterday’s mindsets, experience, models and day-before-yesterday’s knowledge-base. Incremental developments of the past can no longer be options when the complexities and the uncertainties associated with the new generation of water problems are increasing almost exponentially.

Reliable forecasting of the future that is actionable is a vastly complex and difficult task, not only for the water sector but also for all other areas. However, one fact can be predicted with complete certainty: the world in 2050 will be vastly different to what it is today.

The changes during the next three decades will come from all parts of the world, from different sectors and disciplines, from academia, businesses, public sectors and non-governmental organisation (NGO) communities, as well as from rapidly changing social attitudes and perceptions and steadily advancing aspirations from people from all over the world. Taken as a whole, these changes will be far-ranging, far-reaching and far-embracing. All of these will have ramifications for water management.

The water sector has always been an integral and essential component of the global systems. It will be affected by the future global changes, and, in turn, will affect them. These constant interactions will create numerous feedback loops that will be difficult to predict and even harder to manage. Most of these changes are likely to originate from non-water sectors and, seemingly, from non-water-related issues on which the water profession will have, at best, limited say or control. All these will make water management beyond 2030 an exceeding complex task, and this complexity will only increase progressively with time. The extent, magnitude and typology of the future water problems and their solutions will vary from place to place as well as over time. Consequently, water planning and management processes and practices are likely to change more during the next 20 years compared to the past 100 years. Most of the catalysts that will be driving these changes will come from outside the water sector but they will have profound implications on how water is managed.

The water profession has mostly ignored global forces that are often external to the sector even though such forces are already shaping water use and availability patterns (both in terms of quantity and quality), as well as planning and management practices. These forces will continue to increase progressively into the future. Unfortunately, the water profession has mostly neglected, in the past, the various water-related implications of the forces of globalisation, ageing society, free trade, and the information and communication revolution. Taken together, these developments, and others associated with them, will unleash forces that are likely to affect water governance in a variety of expected but mostly unexpected ways. When assessed perceptively, systematically and holistically, their impacts are already visible in all countries of the world, ranging from the USA to Uruguay, and from China to Cameroon. The impacts of these unleashed forces are only likely to increase in the future.

There is no question that future water-related issues and problems of the world will be very different to those witnessed in the past or that are being encountered at present. Historical knowledge and recent experiences will become increasingly inadequate to identify the future water problems, let alone their magnitudes and solutions. New lenses are urgently needed through which future water-related problems can be properly identified, viewed and analysed. The solutions to the new sets of emerging and evolving problems will require new insights, coordinated multidisciplinary, multisectoral knowledge and skills, adoption of new and innovative approaches, adaptable mindsets, and proactive, functional and efficient institutions that can adopt promptly and successfully new scientific, technological and management breakthroughs.

All the signs indicate that many of the currently accepted paradigms and models may have to be extensively modified, and, in some cases, may even have to be completely jettisoned. Many of the current popular paradigms, like integrated water resources management and integrated river basin management, have long passed their ‘sell by’ dates even though they are still being extensively used. New functional and usable paradigms have to be found that should have the potential to solve future global and national water-related problems. These new approaches and analytical tools must be able to manage diversified, even contradictory, requirements of different stakeholders and their social, economic and political agendas, changing public attitudes, perceptions and aspirations, and metamorphosing needs of institutions at various governmental levels. To these challenges must be added water-related implications of increasing and changing structure of the global population, rapid technological changes, relentless economic competitions between countries and within countries, concurrent and conflicting impacts from the forces of globalisation and antiglobalisation, forces unleashed by climatic changes and fluctuations, and rapidly increasing aspirations of people from all over the world for a continually advancing standard of living. Since water is one of the very few common threads that connect all these and nearly all other development factors, water management in the coming decades will become increasingly more and more complex with time.

This book attempts to anticipate and analyse many of the global water challenges of the future. Our contributors who are leaders in their respective fields come from different sectors, disciplines and countries. Together, they provide a unique vision and perspective to see how the world of water is likely to change over the coming decades, and how these changes can be managed cost-effectively and also in a timely manner.

We are most grateful to many people for the idea behind this book and then for helping us to make it possible. First and foremost is Philippe Rohner of Pictet Asset Management who introduced us to the relevance and importance of megatrends for managing water in the future. We are delighted that Philippe could join us as a co-editor. We are also indebted to all the contributors who promptly accepted our invitations to write the specific chapters. After the first drafts were ready, the authors met in Singapore to review and critique all the chapters over two days. Based on these extensive and in-depth discussions, all the chapters were modified by their authors. We very much appreciate that Masagos Zulkifli, Minister of Environment and Water Resources, Government of Singapore, kindly agreed to write the Foreword to the book. Last but not least, we would also like to thank Thania Gomez of the Third World Centre for Water Management, Mexico, for all her editorial help to finalise the manuscript.

According to an African proverb, tomorrow belongs to the people who prepare for it today. We hope the process that first started in Geneva and Mexico, and then later continued in Singapore, will help water professionals from all over the world to appreciate and better understand the nature of the likely water problems of the future.

Singapore

Asit K. Biswas
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Chapter 1
Assessing Global Water Megatrends

Asit K. Biswas and Cecilia Tortajada

> *If you can look into the seeds of time,*
> *and say which grains will grow and which will not, speak then unto me.*
>
> William Shakespeare in Macbeth.

Abstract Currently some 2.5–3.0 billion people do not have access to clean water. To ensure all these people and an additional 2.3 billion people expected by 2050 have access to adequate quantity and quality of water for all their needs will be a very challenging task. Future water-related problems and their solutions will be very different from the past. Identification and solutions of these problems will require new insights, knowledge, technology, management and administrative skills, and effective coordination of multisectoral and multidisciplinary skills, use of innovative approaches, adaptable mindsets and proactive functional institutions. Many of the existing and widely accepted paradigms have to be replaced in the future turbulent and complex era of widespread social, economic, cultural and political changes. The new paradigms must accommodate diversified and contradictory demands of different stakeholders and their changing economic, social and political agendas. Rapidly changing global conditions will make future water governance more complex than ever before in human history. Water management will change more during the next 20 years compared to the past 100 years. Policies and strategies that are future-oriented need to be formulated, which can reform public institutions, satisfy evolving social and economic aspirations and concurrently overturn decades of water misuse and overexploitation. During the coming uncertain era, water policies have to juggle regularly with competing, conflicting and changing needs of different users and stakeholders and simultaneously ensure water, food, energy and environmental securities. Water is one of the few common threads that will bind the development concerns of the future. In the wake of the revolution taking place in water management, many long-held concepts are likely to

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disappear completely. New paradigms and models need to be developed to successfully meet the water challenges of the next three decades.

Keywords Global water future · Water megatrends · Population
Urbanisation · Water scarcity · Water infrastructure · Millennium Development Goals

1.1 Setting the Scene

Predicting future trends in any field is a difficult and complex process. Making predictions is also an imperfect science. During the past several decades, scientific knowledge to predict future trends has grown steadily. However, even in spite of such advances, the capacity to predict the future reliably has not advanced that much to make any significant difference in formulating long-term national policies. Whatever advances there have been, unfortunately, are much less that those needed and desirable for long-term policymaking purposes.

This lack of progress has been due to the complexities of different issues that appear to be growing at a much faster rate than our knowledge and capacity to predict, analyse and assess them. Every challenge facing the world and the myriads of interacting and interrelated issues that could affect that challenge directly, indirectly and tangentially are continuing to evolve rapidly in known and unknown ways. These issues continue to mesh, collide and/or interact with each other in different ways because of changing economic, social, cultural, political, environmental, scientific, technological, ethical and many other associated conditions. Such a state of affair means that whatever trends that can be discerned are being affected by rapidly evolving global and national landscapes of expected, unexpected and uncertain events. Many of these trends converge but others diverge and their interrelationships may often vary with time. These often contribute to the development of complex feedback loops that are difficult to predict and may again change significantly over time and space.

Further, uncertainties and ambiguities need to be superimposed on these complexities because of rapidly increasing disruptive technologies, which are becoming increasingly more frequent over time. These are then further complicated by the emergence of totally unexpected events such as the 2008 financial crisis, which affect every sector in different, appreciable and unpredictable ways. No one was able to predict this crisis in terms of magnitude, extent and duration before it occurred. Add to this plethora of complexities expected events such as climate change whose actual implications over space and time over the next several decades are mostly unknown and unpredictable at present. Accordingly, it is not easy to predict what kaleidoscopic patterns or trends may emerge in various water and water-related fields in the coming years and decades, globally, regionally, nationally and sub-nationally.

Over the past several decades, the main preoccupations of governments and society have been events of the recent past, current events and likely possible developments at most three to six years in the future that may define a country's electoral cycle. The issues considered are often primarily local or national that directly affect specific groups of communities. All these make it very difficult to discern what may be changing over longer time horizons, the magnitude, extent and distribution of these changes over space and time, and why and how they may impact different segments of society in positive, negative or neutral ways. Equally, it is difficult to predict whether these trends will be transient or last over longer periods. This will determine the interest and emphasis that should be placed on these trends.

Equally, it is essential to determine what are likely to be the new emerging issues and what may be their potential long-term implications. Thereafter, it is necessary to estimate who may benefit from these forthcoming developments and who may pay the costs. Such calculations are always at the very heart of any democratic or even non-democratic decision-making processes. Only after such studies are properly completed, it is possible to determine what policies should be formulated and implemented to maximise the benefits and minimise the costs, and then what policies may contribute to maximum net benefit to the society that may be socially, economically and politically desirable and acceptable.

Even these considerations of future trends may not be enough. It will be necessary that the forecasts of future trends be complemented with how societal attitudes, values and aspirations may change over time, and what could be their likely implications to the water and water-related sectors. The emerging societal value systems may affect how water should be planned, managed and used in the coming years so that the future aspirations of the society as a whole can be gauged and fulfilled.

A good example of changing societal attitudes and expectations can be seen by examining what happened during the second half of the last century. During the 1950s, 1960s and 1970s, main focus all over the world was on economic development. Unfettered and continued economic growth was one of the most important political and societal goals, to the extent that environmental conditions were compromised by such growth rates. They were taken in stride and considered to be the price of progress that society should consider worth paying. Even as late as 1970, there was not a single country in the world that had a dedicated Environment Ministry. Prior to 1970, even reasonable methodologies to conduct environmental or social impact analyses simply did not exist. Nor was it necessary to get environmental clearances for large water infrastructure development projects. Economic growth considerations reigned supreme.

The societal attitudes to environmental issues started to change very dramatically during the 1970s and 1980s. By the mid-1980s, an overwhelming majority of countries had made it mandatory that any reasonably sized development project must go through an environmental impact analysis. By 1992, there was *not* a single country in the world that did not have a dedicated Environment Ministry that was responsible for clearing projects on exclusively environmental grounds.

Thus, within a short period of only about two decades, societal expectations and importance of environmental considerations radically changed in dramatic ways.

It is thus absolutely essential to understand and appreciate the values and societal attitudes and perceptions that underpin the existing trends, as well as how they may evolve in the coming decades that will influence future policies. Concurrent considerations of evolving value systems and changing trends must thus be considered simultaneously so that the future water management practices or processes can meet the societal goals, expectations and aspirations successfully.

This means that the future-related analyses should not only consider what are likely to be the trends but also how societal perceptions and attitudes may change through which the implications and relevance of the expected trends can be systematically scrutinised and then appropriately assessed. Accordingly, it is essential to determine how societal beliefs, ideas and doctrines may evolve over time. It will be further necessary to envision what may be the next generation of paradigms that will provide the lens through which the water-related trends should be viewed, analysed and then incorporated in policymaking frameworks.

Accordingly, identification of potential worldviews is needed within which existing and emerging trends can be properly studied and then adequately incorporated into future policies. This may provide an understanding as to why certain trends emerged and continued to thrive but others, after a short period, petered-out. This will give a better understanding of how new global trends may be evolving and their lasting power. Furthermore, how, and to what extent, planning for desired outcomes may affect the dominant views, cultures and paradigms of the future at specific periods of time.

Unless such complex and comprehensive studies are conducted and the policymakers and analysts understand how the future global societal and development landscapes are likely to change, there is a strong possibility that seemingly good ideas may precipitate sub-optimal, or even socially unacceptable, and undesirable outcomes. The reverse may also equally likely to be true.

Unquestionably, predicting the future trends that may affect the water sector in a reasonably and reliable manner is a most challenging task under the best of circumstances. However, one fact is certain. Unless water management practices and processes are significantly improved within a decade or so, more and more countries and cities are likely to face serious and prolonged water security problems: types, magnitudes and extents of which no other earlier generations had witnessed or had to cope with. This is because there will be several major developments that are bound to occur during the next several decades that will affect water management practices and processes in significant ways. Only a few important ones will be discussed here.

First and foremost is the fact that the world population will continue to increase. Between 2015 and 2050, the global population is estimated to increase by 2.3 billion. This means that if future water management practices only improve incrementally, as has been the case in recent decades, significantly more parts of the world will witness serious problems due to increasing scarcities and steadily declining water quality conditions. Already, at least some 2.5–3.0 billion people do not have access to clean water that can be safely drunk without significant treatment at household level (Biswas 2014). If it has not been possible to provide clean water even to current global population after nearly four decades of sustained efforts, how can safe water be provided reliably to an additional 2.3 billion people in only a little over three more decades? In other words, in little over three decades, the world must provide clean water to an additional 4.9–5.4 billion people, a truly Herculean task under the best of circumstances.

In addition to a higher population, there are other factors that could ensure total global water requirements will continue to increase for decades if water management persists to improve only incrementally in the future. Some of these factors will be briefly discussed herein.

Developing countries are witnessing sustained urbanisation. Already, for the first time in human history, more than half of the global population live in urban areas. This percentage will advance steadily in the coming decades. As the urban centres grow, greater quantity of water has to be imported from the hinterlands to meet their water needs. The marginal costs of bringing additional water over increasingly longer distances are rising rapidly, as are the environmental and social costs. In addition, the population of the hinterlands and their economic activities are also likely to increase further in the future. Accordingly, their water requirements are going to increase as well. People in the hinterlands are already becoming increasingly reluctant to export water to the cities for which not only they do not receive any perceived economic benefits but also lose control of their own water sources, which they would need themselves in the near future for the development of their regions.

In addition to physical scarcities, another equally important problem has been regular deterioration of quality of all water bodies within and around urban centres of the developing world, and in many cases even in the developed world. This is because management of wastewater in developing countries has been grossly neglected in the past. This neglect is likely to continue for much of the developing world in the foreseeable future. Thus, cities are running out of water due to continuing mismanagement of this resource and concurrent contamination of their water bodies with known and unknown pollutants, making such sources unsafe for consumption without sophisticated and expensive treatment. Since nearly all cities in developing countries provide free or highly subsidised water, water utilities do not have necessary funds and technical and management expertise for treating contaminated water sources properly, which are becoming progressively more and more polluted.

Furthermore, as the number of middle-class households in the developing world has exploded in recent years, and will continue to do so during the next several decades, the total water requirement is increasing significantly. These middle-class households are likely to demand reliable availability of water, electricity, consumer goods, protein-rich food and employment opportunities in good-paying manufacturing and service industries. None of these requirements can be fulfilled without either more water and/or significant improvements on how this resource is managed at present. Globally, nearly 70% of water is used for agriculture. As households become richer and more literate, their diet changes from being cereal-based to more significantly protein-rich. Ensuring a protein-rich diet is available means use of significantly more water. This trend is likely to continue for the next several decades. Agriculture now accounts for 70% of all global usage. While in absolute terms the global agricultural water use is increasing, in percentage terms it has been steadily declining for well over a decade. In contrast, in percentage terms water use for industry and electricity generation has been steadily increasing. In future, there simply will not be sufficient extra water for producing significantly more protein-rich foods that the middle class will demand.

The world is now facing a perfect storm in terms of water availability and management. Demands for water are rising significantly for various reasons but new sources of water are becoming increasingly more expensive and difficult to produce. Water is not only an existential issue but also is an essential requirement for economic development and good quality of life. Even though the importance of water is widely recognised throughout the world, there is not a single country at present anywhere where water has been consistently high-up in the political agenda during the recent decades. It only becomes a political priority when droughts, floods or other natural disasters occur. As soon as these events are over, water simply disappears from the political agenda until the next catastrophe. This is despite the well-established fact that water problems cannot be resolved on a long-term basis with only short-term ad hoc political decisions. At present, there is no indication that the sector is likely to attract long-term consistent political support that is essential for ensuring global water security.

1.2 Changing Global Water Landscape

The future water-related problems are likely to be different from those of the past or that are being encountered at present. While historical knowledge and past experience are always useful to understand and appreciate the genesis of the problems, new lenses are necessary through which they should be viewed and analysed. Identification, analysis and solution of nearly all future water-related problems will invariably require new insights, coordinated multidisciplinary and multisectoral skills, innovative approaches, adaptable mindsets and proactive institutions. In addition, many of the currently held beliefs and widely accepted paradigms may have to be jettisoned and new functional and implementable approaches found that should have the potential to solve future global water problems.

Historical developments, as well as many of the existing analytical tools, are becoming increasingly irrelevant in the new and turbulent era of societal changes, economic and political developments and water availability and use patterns. Water management practices will have to accommodate diversified, even contradictory, demands from different stakeholders and their economic, social and political agendas, institutional requirements and a sceptical media with varied interests and agendas. The situation is likely to become even more complex due to rapid technological changes, relentless economic competition between countries and within countries, concurrent and even conflicting demands from the forces of globalisation and antiglobalisation, and intensifying pressures from single-cause activist non-governmental organisations (NGOs). All these and many other associated factors will affect how water is managed, directly or indirectly, in the future.

Currently, major changes are taking place in many different aspects of water management. The majority of water professionals are not even aware of them, let alone what could be their medium- to long-term implications. In the wake of this future era of continuing significant changes, many long-held popular concepts and paradigms of water management will undergo rapid evolution. Some are likely to disappear altogether, replaced by new and more appropriate and applicable paradigms. Never before in the history of water management has such profound changes taken place that are likely to be witnessed during the next two to three decades. Water management practices during the next couple of decades will change more than they have during the past 100 years. Many of these changes will come from non-water related sectors such as food, agriculture, energy, environment, economy and societal changes in attitudes and perceptions on which the water profession will have limited or no say, or control. Such external pressures are likely to make water management during the post-2030 period exceedingly complex and a difficult task.

Let us consider how a few selected issues have changed or are changing, and how some of the popular paradigms are becoming no longer relevant for managing water sustainably.

1.2.1 Domestic Water Supply

A good example of how some of the global perceptions and attitudes are changing is from the domestic water supply sector. Surprisingly, even though water has always been essential for human survival, it was not on the global development agenda until the early 1970s. During the UN (United Nations) Conference on Human Settlements, held in Vancouver, Canada, in 1976, the issues of universal access to clean water and sanitation came up for the first time in a serious and sustained way. These issues were further discussed during the UN Water Conference, held at Mar del Plata, Argentina, in March 1977. This Conference proposed that the UN should declare the 1981–1990 period as the International Water Supply and Sanitation Decade (Biswas 1978). The recommendations of Mar del Plata were approved by the UN General Assembly, and thus the issue of clean water for all humanity was put firmly on the global agenda for the very first time as an important target to be met.

The objective of the Decade was ambitious. It aimed to provide everyone in the world with clean water by 1990. The Decade successfully increased the access to water for hundreds of millions of people throughout the developing world. During the Mar del Plata Conference, the consistent focus was access to ‘clean’ water (Biswas 2004). For example, its Secretary General, Yahia Abdel Mageed, categorically stated in his opening address that ‘clean’ water should be accessible to all

(Mageed 1977). The idea during the Mar del Plata Conference was that the Secretariat of the Decade should be independent.

Following the approval of the Decade by the UN General Assembly, the World Health Organisation (WHO) successfully lobbied so that the Secretariat of the Decade was located within the WHO. It was also decided that the WHO and the UN Children's Fund (UNICEF) should jointly monitor how the Decade objectives were being met.

The WHO and the UNICEF then changed the narrative completely by proposing the idea of 'improved sources' of water in contrast to 'clean' water. The definition of 'improved sources' of water was deliberately left vague. Individual governments basically decided what they considered to be 'improved sources', irrespective of whether water was clean or not.

Shortly after the Decade started, and for some 35 years thereafter, the UN Agencies and the World Bank and other development banks have consistently misrepresented and obfuscated the national and the global drinking water situations. The discussion at Mar del Plata had two main goals. First, people should have easy access to water, and second, water should be clean to drink without any perceived or real health hazards.

In terms of access, people all over the world always had access to water: otherwise they could not have survived. The Decade's focus was on easy access. Unquestionably, the Decade made access significantly better for hundreds of millions of people living in both urban and rural areas of the developing world. This, by any standard, must be considered a remarkable achievement.

Where the UN agencies and development banks have failed miserably is on the quality of water that people have access to. Unfortunately, the meaningless terminology that has been consistently used by the international organisations, 'improved sources' of water, never had any relation to, or consideration of, its quality. Since 'improved sources' is such a vague term, the quality of water may have had declined significantly and still could be accepted as an 'improved source'. It all depended on how each individual or institution interpreted this ambiguous and amorphous term.

The issue has been consistently obfuscated since these international organisations have used 'improved sources', 'clean' and 'safe' water interchangeably from the early 1980s onwards. This may have been deliberate since it would allow them to claim success and also show that the targets have been met within the stipulated time. Consider the 2016 report by the WHO and the UNICEF on the global progress on water supply and sanitation. In the very first paragraph, the report mentions 'safe drinking water' (UNICEF-WHO 2016). In the second paragraph, it switches to 'improved sources of water'. This has been the consistent pattern over the past three decades. The net result of this dubious practice has been that it is now accepted globally by almost everyone that 'improved sources' mean clean and safe water. This obfuscation has made various UN Agencies and development banks claim that the Millennium Development Goal for water was reached well in advance of the target date of 2015. Nothing, of course, is further than the truth.

The absurdity of this claim becomes obvious when the UNICEF and the WHO (2016) misleadingly and totally erroneously claimed that some 663 million people in the world lack safe water. The nature, extent and validity of this dubious claim can be realised by considering only the South Asian countries. Together they have some 1.7 billion people. Unfortunately, there is not even one city, town or village in any South Asian country where citizens have access to safe water that could be drunk from a tap, or source, without any health concerns. Globally, there are least 2.5–3.0 billion people who still do not have access to safe water. This estimate is around four times the currently accepted figure. Thus, the magnitude of the problem is significantly greater than what it is universally believed at present(Tortajada and Biswas 2017).

Another issue that has not received enough attention is how much water a person needs each day to lead a healthy and productive life. In the framework of the global discussions on human rights to water, and depending on the countries and institutions concerned, it has been generally considered to be between 50 and 150 L per person per day. These figures are not based on any scientific or medical study but are decided simply on an ad hoc basis by different countries.

The only study to estimate an amount of water a human being needs to maintain a healthy and productive life was carried out in Singapore between 1960 and 1970. It showed that beyond 75 L per capita per day, there did not appear to be any appreciable and additional health benefits (Biswas 1981). The additional water used beyond 75 L was primarily aesthetical, and not related to health reasons or concerns.

There is considerable merit to the results of the Singapore study. With a strong emphasis on water conservation and good management practices, several European cities have now reduced their per capita daily water consumption to between 90 and 100 L. These figures are still declining. It is likely that by 2030, many cities may be able to reduce their per capita daily consumption to 80–85 L, not so different from the results of the Singapore study.

The implications of this finding are important. It means that not only less water may be needed for each healthy person than considered necessary at present, but also less water and wastewater have to be properly treated. Less water used will result in less wastewater generation. In other words, with good management, availability of adequate quantity of drinking water even in the most arid countries should not be a problem, not only now but also by 2050 when the world is estimated to have over two billion extra people.

What will continue to be a problem is the continuing deterioration of water quality, especially in developing countries where domestic and industrial wastewaters are seldom adequately collected, taken to plants for proper treatment and then discharged to the environment in safe and acceptable ways. The pollution problems are further intensified by agricultural runoffs of fertilisers and pesticides. Even developed countries have not managed to control agricultural runoffs properly, as well as discharges from large scale feedlots. For most developing countries, control of agricultural runoff is still not on the political radar.

As population and industrial activities have steadily increased in the developing world, neglect of wastewater management has meant that all water bodies in and around urban centres are now already severely contaminated with many harmful pollutants. Except for a few countries, there are still no signs that the politicians are taking water quality management seriously. Herein lies one of the major future water challenges for the developing world: how to provide clean water to a steadily increasingly population when water sources have already been seriously polluted and are highly likely to become even more contaminated in the future with hazardous chemicals. Thus, the total stock of water that can be cost-effectively used for drinking purposes is steadily decreasing in developing countries due to quality considerations.

While the global preoccupation in the past and the present has been primarily with the physical scarcities of water, a more serious problem for the future must certainly be the quality of water and the associated health and environmental impacts.

Neither the water profession nor the rest of the world has appreciated the complexities and difficulties of proper and efficient water quality management. The complexities of managing water quality have steadily increased over the past half century. For example, in the 1950s and 1960s, the best water utilities in the world used to monitor about 30–40 water quality parameters, and average utilities around 15–20 parameters. Quality of water sources were significantly better than what they are today. Environment and health considerations and awareness of the public to these issues were much less than at present. Equipment available for water quality monitoring in the past was not highly sophisticated and inexpensive and easy to operate. Only very few, if any, pollutants used to be measured in concentrations of parts per million. With the acceleration of industrial activities, numbers of chemicals, heavy metals and other hazardous chemicals in wastewaters have increased significantly. Equally, many pollutants need to be measured in ever-lower concentrations. Instrument technologies have advanced rapidly in recent decades. Thus, it has become possible to measure parts per billion, and even parts per trillion.

In addition, up to about 1970, most water utilities in the developed world used to monitor about 30–40 quality parameters. This number has steadily increased over the past 40 years. Figure 1.1 shows the number of water quality parameters that PUB Singapore's National Water Agency, has been monitoring from 1963–2016. The number has increased from about 36 in 1963 to about 340 in 2016, a 940% increase within a period of 53 years (Fig. 1.1). In the future, as many emerging contaminants are likely to become important, the total number of pollutants that must be monitored will increase further. Most of these pollutants require measurements for tiny concentrations of parts per trillion. This will be an expensive and difficult process.

Monitoring and analysing the ever-increasing number of parameters are beyond the capacities of all developing countries. Not only they do not have the funds to buy the instruments that are becoming increasingly more sophisticated and thus steadily expensive but also they simply do not have enough trained manpower to operate and maintain these instruments and subsequently analyse and assess regularly the implications of the monitored results, especially if they should indicate any problem.

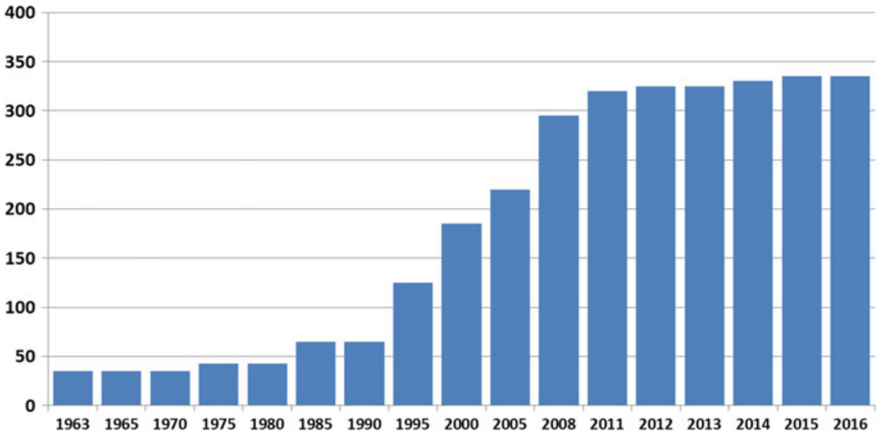

Fig. 1.1 Number of water quality test parameters monitored by the PUB, 1963–2016. *Source* Compiled by PUB at the request of the authors

These are only some of the issues facing the domestic water sector now and in the future. While their magnitudes, intensities and complexities are increasing, typology of the problems encountered has been around for decades.

In addition, there are new types of issues that are surfacing which water utilities have not encountered before in any sustained fashion.

Globally, people all over the world appear to be progressively losing trust in the quality of water supplied by the utilities, irrespective of the actual quality of water supplied. In developing countries, the trust was never present for decades. Consequently, each household has been forced to become a mini-utility to manage their own individual water supply. First, they had to build an underground storage tank where water could be stored when it is supplied for only a few hours each day. Water is then pumped to an overhead tank as and when needed. This ensured that households had 24 × 7 water supply even though utilities supply water for only 3–5 h each day. Water then had to be treated before it could be drunk without any health risk. Some 10–20 years ago, households mostly used simple carbon filters to purify water. Nowadays, with water sources becoming increasingly more contaminated and people becoming more aware of health implications, households are often using membrane technology for purifying water. Membrane technology, as used at present, is highly inefficient. Nearly 60–65% of water treated must be thrown out at present.

Changes are now also occurring in those cities in developed countries where utilities have provided clean water for decades. Residents in cities such as New York, London, Berlin, Singapore or Tokyo have increasingly stopped drinking water supplied by the utilities even though quality has not been an issue for decades. Use of bottled water for drinking has now become increasingly common. Households are now treating their own water before drinking. Point-of-use water treatment systems are becoming increasingly common, even though they are not necessary and are becoming more sophisticated and expensive to buy, operate and maintain. In cities such as Singapore and Hong Kong, the majority of households continue to boil water before drinking, even though quality has not been an issue for decades.

The water profession has still not realised that people in both developed and developing countries are steadily not using water from the utilities even when their quality is good. Why this loss of confidence and trust is occurring globally is difficult to say. It is probably for a variety of social, cultural and aspirational reasons, and these may vary from city to city. Only a few important ones will be noted here.

First, there have been several well-publicised failures of water supply systems in the Western World. In 2010, seven people died in Walkerton, Canada, and 2300 people felt ill due to devastating outbreaks of waterborne diseases. Cryptosporidium infections in cities such as Milwaukee, Melbourne or Adelaide have not helped to instil trust in utilities. Equally, well-publicised events such as lead contamination in Flint and Hong Kong have raised questions on the quality of tap water people are receiving and drinking.

There are also perceptional and aspirational issues. Companies selling bottled water and point-of-use water treatment systems have successfully transformed water into a lifestyle issue by enticing advertisements. While they have never implied that water supplied by utilities in the cities of the developed world is not safe to drink, they have managed to convince consumers that the alternatives they offer are vastly superior, and thus desirable and preferable for their families. In contrast, not even a single utility in the developed world spends any funds in elevating tap water to be an aspirational lifestyle issue. Furthermore, utilities cannot afford to have an advertising budget that is even a small fraction of those selling bottled water and point-of-use treatment systems. They are always under pressure to keep the cost of water to a minimum. Thus, it is likely that utilities will steadily lose their share in the drinking water sector in the coming decades in most parts of the developed world.

1.2.2 Large Water Infrastructure

A major development of the post-1975 period was the emergence of a progressively stronger environmental and social movement. This movement, which developed over a short period of years radically changed societal attitudes and perceptions on all issues relating to the environment. The importance of this movement can be realised by the fact mentioned earlier. In 1970, there was not a single country in the world that had a dedicated environment ministry. Some two decades later, by 1990, one would have been hard pressed to find a single country that did *not* have a dedicated environment department.

Environment, now, has become rightfully a mainstream consideration. Environmental Impact Assessments have now become mandatory in nearly all countries of the world. Proper consideration of environmental issues of all development projects was undoubtedly a most welcome development. Unfortunately, in the real world there are very few, if any, major developments that contribute only to positive outcomes and have no negative implications. This has also been true for the new environment movement.

For reasons that are still difficult to identify, and regrettably not properly researched, construction of large dams became the lightning rods for many environmental activist groups. This started to become evident in the 1980s, and picked up steam during the early 1990s. The environmental activists initially came primarily from the developed world where the era of construction of large dams was generally over by the 1970s. They provided financial, intellectual and media support to their counterparts in the developing world to oppose, steadfastly, construction of large dams irrespective of their net social and economic benefits.

These single-cause anti-dam activists from the developed world already had a decent standard of living, including access to clean water, proper sanitation, electricity and food, as well as good employment opportunities. In order to promote their single cause anti-dam agenda, they often eschewed scientific and technical facts, and frequently quoted data and statements that were erroneous or out of context. In an era that universally considered ‘small’ was always ‘beautiful’, large dams automatically became ‘bad’ or ‘ugly’, irrespective of their desirability and overall benefits to the society. These activists successfully managed to propagate the myth that water, energy and food problems of the developing world could be successfully resolved by small dams and water harvesting techniques that would have very minor social and environmental costs. They also successfully portrayed to the media how large dams have universally contributed to major social and environmental costs, but very limited, if any, benefits. This, of course, was mostly untrue. However, the media always look for critical stories. These stories served their purposes well and were given significant publicity.

There is no question that small dams can play important roles in rural and smaller urban areas to meet their water needs. Equally and undoubtedly, they will not be able to meet the water requirements of larger urban-industrial complexes, where demands are already high and increasing; population is growing due to natural causes, and urbanisation, economic activities are expanding; and rainfalls often may not be enough and are always erratic.

The opposition to large dams reached its peak around the mid-1990s. In 1993, facing certain defeat in the Executive Board, India withdrew its loan from the World Bank amidst a global controversy over the construction of the Sardar Sarovar project. In the same year, 1993, the World Bank established an Inspection Panel as an independent complaints mechanism for people and communities who believe they have been, or likely to be, adversely impacted by any World Bank project. Not surprisingly, nearly all the projects the Inspection Panel considered during the 1990s were related to dams.

In the cacophony of anti-dam rhetoric in the 1990s, the Sardar Sarovar project became the ‘Vietnam’ for the World Bank in terms of funding support to dam construction projects. The financial support for large water infrastructure projects by the World Bank, Asian Development Bank, Inter-American Development Bank, and all other major bilateral donor agencies declined precipitously due to the success of the opposition from the anti-dam NGOs and lobby. The media became enamoured by the claims of the activist NGOs. Furthermore, dams are invariably constructed in inhospitable regions with poor transportation and communication facilities. Thus, very few media people actually verified the claims of these activist NGOs and simply published their unsubstantiated and often dubious assertions as facts.

A decade later, the World Bank and other development banks realised their folly, and reinstated funding of large dams. In fact, for nearly two decades it has been known how adverse environmental and social impacts of large dams can be minimised and positive benefits can be maximised so that their net benefits to the society can be greatest. During this period, it was consistently advocated that the people who have paid, or were likely to pay, the costs for earlier large water infrastructure projects should be made direct beneficiaries, and this should be seen as a development opportunity and not as a cost or constraint. This is especially true for people required to be resettled: they must have better lifestyles compared to what they used to have before the projects were constructed.

During the post-2000 period, the traditional development banks and bilateral aid agencies have been forced to re-examine their approaches and views because of the rapid emergence of Chinese institutions such as its Export-Impact Bank and China Development Bank. These two banks, by 2010, were providing more export funding compared to all the Group of Seven (G7) countries combined. Similarly, by 2010, the two Chinese banks were providing more loans on an annual basis than the World Bank. Not surprisingly, the World Bank and G7 export financing institutions have witnessed a steady decline in global influence since 2000 in terms of infrastructure construction because of their inconsistent policies.

The narrative further changed when a China-led multilateral development institution, the Asian Infrastructure Investment Bank (AIIB), was formally established on December 25, 2015. This happened despite the fact that both the USA and Japan lobbied strongly and consistently against its formation. The AIIB currently has 80 countries whose memberships have been approved. This is the first time a development bank is led by a developing country.

The emergence of the Chinese banks and the AIIB has changed the global narrative on infrastructure development, including of large dams. Further, the World Bank and all regional development banks realised, by 2000, that they had made the wrong decision by reducing funding significantly for the construction of large dams. Even after their increased funding, the rapid emergence of the Chinese banks has meant that the older financing institutions can no longer dictate the global narrative on construction of major infrastructure projects.

An important side benefit of this emergence of the Chinese support has been that the global discussions on dams have now become consistently more fact-based and nuanced since about 2000. This trend is likely to continue through the next couple of decades when other major countries such as India and Brazil become increasingly involved in providing export credits for construction of large dams in other developing countries.

1.2.3 Integrated Water Resources Management

The concept of integrated water resources management (IWRM) has been around from the late 1930s. For much of the 1940s, 1950s and 1960s, it was known as comprehensive water resources development. The UN was promoting this concept as early as the mid-1950s. Unfortunately, for a variety of reasons, it was not possible to operationalise it. Thus, slowly it lost traction during the 1970s and 1980s (Biswas 2008).

IWRM received a new lease life in the 1990s. It was not because ways had been found to use it effectively in the real world to improve water management but because of several political and institutional developments and vested interest from some Western donor countries.

The main reason of its re-emergence was, in January 1992, the UN System organised an International Conference on Water and the Environment in Dublin. The World Meteorological Organisation (WMO) took the leading role for its organisation. This Conference was expected to formulate sustainable water policies and programmes for consideration by the UN Conference on the Human Environment (UNCHE) that was held in Rio de Janeiro, in June 1992. UNCHE was attended by most heads of states from countries all over the world. An objective of the Dublin Conference was that its deliberations and recommendations would help to place water high-up in the global political agenda during the Rio meeting.

The Dublin Conference failed spectacularly to achieve its objectives for two main reasons. First, and most surprisingly, its main proponents had no idea about the rules governing UN mega-conferences. It was organised as a meeting of experts and not as an intergovernmental meeting. The rules of such UN World Conferences stipulate that the Rio meeting could only consider recommendations from intergovernmental meetings and not Expert Group meetings such as Dublin. Thus, some governments objected at Rio to discuss the results of the Dublin Conference.

Second, intellectually Dublin was basically a ‘SOS’ (same old stuff) type of conference. It did not discuss any idea that could be new or innovative. Poorly planned, managed and executed, and devoid of any serious intellectual content, it was unanimously considered by the participants of the 1992 Stockholm Water Symposium to be an abject failure.

For about a decade, the prime movers of the Dublin Conference, a few UN agencies and bilateral donors, spoke glowingly of the four so-called Dublin principles, which were bland and politically correct statements of the obvious. These, even if the principles could be implemented by a miracle, could, at best, improve water management only marginally.

One important, but not meaningful, development happened following the Dublin Conference. The donors, notably the World Bank and the United Nations

Development Programme (UNDP) and some governments, especially Sweden, went on to establish a Global Water Partnership (GWP). The leading figures of Dublin Conference were also the dominant founding figures of the GWP. Not surprisingly, the GWP's initial programme focused on the four Dublin principles. After spending millions of dollars on the programme based on these four principles, the GWP found that it received no traction or global interest.

The GWP then began to promote IWRM as the primary focus of its programme. It was also included in the Dublin recommendations. Most unfortunately, the then leaders of the GWP were mostly unaware that IWRM concept was tried in the 1940s, 1950s and 1960s under a different name and, even after three decades of effort, it did not work.

Not being aware of IWRM's history, the GWP claimed that 'IWRM draws its inspiration from the Dublin principles'. Not only this was totally incorrect but the Dublin principles had very limited relation to IWRM.

With the GWP and its supporting donors pumping hundreds of millions of US dollars to promote IWRM, it became a powerful all-embracing paradigm during the 1995–2005 period. This is despite the fact that, operationally, it has not been possible to identify even one major water development project anywhere in the world that has been planned and managed in such a way that it could inherently become integrated, irrespective of how it is defined. On a scale from zero to 10, zero being no IWRM and 10 being full IWRM, it is not possible to identify even one significant water project anywhere in the world that could receive a grade of three. This is also valid for those donor countries who have been promoting IWRM vigorously and strenuously for over two decades in the developing world.

Even after two decades of relentless promotion by donors that IWRM is the *nirvana* of water management, there is still absolutely no agreement among its promoters as to what this concept exactly means (Giordano and Shah 2014), what are the issues that should be integrated, whether such integration is possible or even desirable, and if by a miracle such integration was possible, would it improve water management appreciably? Most surprisingly, these fundamental questions have never been asked by its proponents, let alone answered.

Extensive analysis of IWRM literature published during the past 20 years indicated at least three undesirable developments. First, there is no clear understanding what IWRM exactly means. Different institutions and water professionals define it very differently. The absence of any usable and implementable definition and measurable criteria has only compounded the vagueness of the concept and has reduced implementation potential to a minimum.

Second, because of the resurgent popularity of the concept and amount of serious money that was spent by the donors to promote the concept, many water professionals and institutions decided to do what they have been doing already, but under the guise of IWRM to attract additional funds and attention. Third, even after the donors have spent heavily to promote the concept, the results of IWRM have been very meagre and not discernible.

Accordingly, the GWP's IWRM toolbox contains cases that have, at best, only tangential reference to the concept. Equally, no serious objective and independent studies were conducted as to whether the case studies actually produced true and lasting results.

In one aspect, IWRM has been highly beneficial to the donor countries. The tremendous amount of funds they have spent has ensured that their nationals received employments as IWRM experts, educational institutions are being supported with funds and students studying IWRM and equipment manufacturers in their countries are being bolstered by this funding. About 70–80% of the donor funding returns to the donor countries as salaries for their nationals as 'experts', sale of equipment manufactured in their countries, capacity building by using their institutions and experts and other activities that benefit the donor countries significantly. There is no question IWRM has served the donors quite well. Even in cases where the donor countries have provided funds to multilateral institutions such as the various UN agencies, the World Bank and regional development banks, as funds in trust, the implicit understanding has always been that most of these funds would be spent in the donor countries using their nationals and services.

Concepts and paradigms, if they are to have any validity and usefulness, must be implementable so that they contribute to better and more effective results. Not only this is not happening at present with IWRM but also there are no discernible signs that this is likely to happen any time in the foreseeable future.

In addition, the world is heterogeneous, with different cultures, political processes, social norms, physical attributes, availability of investment funds, planning and management capacities, institutional arrangements and a host of other factors. The systems of water governance, legal and regulatory frameworks, effectiveness of institutions and decision-making processes and people's expectations and aspirations mostly differ from one country to another, often in very significant ways. Thus, a fundamental question that needs to be asked and answered: can any paradigm such as IWRM be equally valid for all countries of the world and for all times despite widely varying conditions? Given the fact that for nearly three generations it has not been possible to implement IWRM, the probability of this paradigm being useful to improve water management is indeed very, very unlikely.

Developing countries on which IWRM was imposed by the donors are slowly realising that the 'emperor may not have any clothes'. A few countries have already reached this conclusion and more are likely to be disenchanted by the ineffectiveness of this paradigm within the foreseeable future. Based on past experiences, it is highly unlikely that the donors will admit that IWRM has not worked in the past, is not working at present and is unlikely to work in the future. The most likely scenario will be that donors will steadily reduce their strong IWRM rhetoric and start focusing on the 'ends' of water management rather than exclusive focusing on one of its many 'means', as has been the case for the past two decades for IWRM (Biswas 2008).

1.2.4 Integrated River Basin Management

Another popular paradigm whose usefulness must be seriously questioned at present is integrated river basin management (IRBM). The idea of using a river basin as a unit for management is not new. It has been around for at least over 200 years. River basins do not follow administrative or political boundaries. Some experts believe that water can be best managed within the framework of river basins but all other resources and economic activities can be managed within administrative and political boundaries.

Accordingly, over the past 200 years, there have been many attempts to manage water at a river basin scale but with limited success. For a select few small river basins that are exclusively within one country they have worked reasonably well, especially where the main management and political concerns have been in terms of water quality and environmental issues, and the central governments of the countries concerned are directly responsible for water management. IRBM has had rather limited success when the countries have federal structure, and constitutionally provinces or states are in charge of water management. Furthermore, the successful cases generally did not have water allocation as an important issue between upstream and downstream regions.

While managing water at a river basin scale has been attempted in nearly every continent, this has not worked well for a variety of reasons. First, is the issue of scale. If the river basins are large, such as Ganges, Brahmaputra, Mekong, Amazon, La Plata, Congo or Nile, and encompass two or more countries, it has not been possible to manage them at basin scale. The complexities of managing large scale river basins are so huge that the situations are unlikely to change any time in the future.

If a river basin like the Ganges is considered, managing it exclusively within the Indian border has not been possible due to its sheer scale, and political, institutional and legal complexities. Even if its main tributary, Yamuna, is considered, its basin area of 366,263 km^2 has also proved too large to manage. The Indian Government tried to split the Yamuna basin into two, Upper Yamuna and Lower Yamuna. Even after this split, it was not possible to manage them due to the complexities involved.

Second, another important issue that the water profession has basically ignored is the characteristics of river basins have changed significantly in recent decades. As major cities needed more water for various purposes, it was often possible only by inter-basin transfer. Accordingly, during the post-1960 period, an increased number of river basins have been interconnected because of increasing water demands.

At present, in several cases these interconnections have become massive. For example, China's south-to-north water transfer project has connected several major river and lake basins. Many examples now exist of similar inter-basin interconnections in countries as diverse as China, India, Brazil, Mexico and South Africa. Such interconnections mean that the areas of many river basins over which they should be planned and managed are increasing steadily. These developments are making them unmanageable due to rising complexities. In addition, lack of good sites where large dams could be constructed and the long distances separating them from potential users of water are becoming serious constraints that may make good and implementable planning at the basin level very difficult to achieve.

As IWRM became popular in recent years, there has been a big push for integrated river basin management as well. Like IWRM, many fundamental questions must be asked about IRBM. Among these are what exactly should be integrated, who will do the integration, is such integration possible or even desirable at basin scales, and would such integration improve water management perceptibly?

In terms of what should be 'integrated', there has been very little serious discussion for IWRM and even less for IRBM. Biswas (2008) identified a consolidated set of 41 issues that different authors or institutions have suggested should be integrated within the context of IWRM. Since these issues are often closely interrelated, directly or indirectly, and are mostly not mutually exclusive, they simple cannot be integrated even at a conceptual level, let alone in the real world. Nor can this integration be possible in the future.

For IRBM, the issues are even more complex in developing countries of Asia, Africa and Latin America because many of the large rivers span several countries. For these trans-boundary rivers, there are mostly no clear and binding regimes for water allocation between the countries concerned that are fair, equitable and sustainable. Furthermore, even when such treaties do exist, as on the Indus River between India and Pakistan, or on the Colorado River between the USA and Mexico, the conditions when the treaties were signed several decades ago in all the concerned countries are very different from what they are at present. While in both the above mentioned two cases some changes have been made to the treaties, these modifications have not been significant. There is very little knowledge and experience available at present on how to negotiate living treaties or how they should be formulated. In fact, serious and sustained discussions as to whether such treaties are even possible, or desirable, have not yet been started.

Attempts at integrated river basin management in major to medium size trans-boundary rivers have often led to poor coordination and sometimes even conflicts. Institutions such as Lake Chad Basin Commission, Mekong River Commission and Nile Basin Initiative (including their predecessors) or Joint Rivers Commission of India and Bangladesh have spent years of efforts and millions of dollars for somewhat meagre results.

The situation in terms of IRBM in countries where the responsibilities of water management lies with the states or provinces and not with the central government, such as in Brazil, India or Pakistan, even managing exclusively national rivers, has not been encouraging. There are many reasons why IRBM has not worked and is not working.

A major reason has been that central and state water institutions continue to have inconsistent, inefficient, substandard and overlapping policies (Tortajada et al. 2018). Even though river basin institutions have existed for decades, data on water availability, use and quality leave much to be desired. Different water institutions use data that are often not reliable or even consistent. Without reliable data over a reasonable time period, it is not possible to efficiently plan and manage any river basin.

Furthermore, what was supposed to be the main conceptual attraction of IRBM has now become its Achilles' heel. Their encyclopaedic responsibilities to integrate various factors and issues has proved to be too complex, onerous and demanding to achieve. These constraints are ensuring that there is fundamental discrepancy between promise and actual performance of IRBM. The proponents of IRBM are facing formidable limitations as to how such a paradigm may contribute to better water management in the real world.

Thus, in the coming decades, many existing popular and even once promising paradigms such as IWRM or IRBM, will undergo very significant modifications, or even disappear altogether completely.

1.3 Changes in Other Areas Affecting Water

Water is one of the very few resources that are essential for activities in other areas of human endeavour. Water is linked with all human activities. Equally, all human activities have direct and indirect impacts on water, both in terms of quantity and quality. In the coming decades, developments in other areas, sectors and changing perceptions and attitudes of human beings to water will have significant bearing on water management, certainly much more than ever witnessed in human history. Thus, activities in other areas will increasingly affect water management practices and processes through many known and unknown pathways.

While developments in all other areas will affect the water sector, only two aspects will be discussed here due to space limitations: implications of future developments in population and urbanisation. These developments will have significant impacts on water, many of which are being basically ignored at present in all existing policies in nearly all countries of the world.

1.3.1 Population

While increases in population have received much attention globally, what is basically being ignored is the implications of structure of population changes that are likely to affect the water sector significantly in the future. An important issue that the water sector is basically ignoring at present is the likely impacts of an increasingly ageing population.

Ageing of the global population is one of the important trends of the twenty-first century. Driven by reductions in fertility levels and increases in lifespans, the number of elderly persons of 60 years or older will steadily increase in both numbers and as a percentage of the population. In 2015, one in eight people globally was elderly. This ratio is estimated to increase to one in six by 2030, and to one in five by 2050 (UN 2015). Globally, the number of older persons is increasing at a much faster rate than any other age group. Furthermore, the number of older persons is growing faster in urban areas compared to rural areas. During the 2000–2015 period, the growth of numbers of older persons in urban areas increased by 68%, compared to 25% in rural areas.

Increase in the elderly population will affect social progress, economic development and resource consumption in a variety of complex and interacting ways. It will affect rates of economic growth, national savings and consumption rates, government revenues and expenditures, housing, infrastructure, health care, pension commitments and intergenerational wealth transfers. In addition, compared to earlier experiences from the developed world, developing countries will be ageing at a much faster rate and more extensively. This will mean that developing countries will have to adjust to the changing conditions more rapidly than the western world, even though the former will have less financial capabilities, limited management and administrative capacities, weaker institutions and less efficient governance policies compared to those developed countries had faced when their populations aged.

Possible implications of an increasing elderly population in the developing world have mostly been neglected thus far. Yet, this is very likely be an important public concern in developing countries within the next 2–4 decades. Thus, appropriate and implementable policies must be formulated in this area. Unfortunately, most of the world does not appear to have much experience in this area.

The interrelationships between water management and an increasingly elderly population is now an unexplored territory. They are likely to influence each other in a variety of ways over time and space. Only a few of these will be discussed here.

First, for rural, peri- and semi-urban areas of many developing world countries, in the absence of water connections and wastewater disposal facilities at household levels, people are forced to use communal land and water bodies for their daily personal hygiene. For a steadily increasing number of elderly people carrying out such routine daily chores, especially when their physical movements become weaker and when their health starts to deteriorate or when they become sick, becomes difficult. With improvements in health care, education, food and nutrition, the lifespan of the people is likely to become longer. Inadequate access to water supply and proper sanitation at home will pose particularly heavy burdens on a rapidly increasing number of the elderly population as well as on their families.

Second, as people get older, their immune systems become progressively weaker. In the developing world, there are some 2.5–3.0 billion people who still do not have access to clean water. People may manage with a poor quality of water when they are younger and healthier. However, as they become older, their immune systems will start to deteriorate. Accordingly, the quality of water will become an increasingly important health concern. The problem may become increasingly serious because quality of ground and surface waters are steadily declining in the developing world due to neglect of water quality management.

Third, as the older generation of people retire from work, considerable knowledge, experience and collective memory will be increasingly lost. In countries such as Japan and South Korea, a significant percentage of knowledgeable and experienced people will retire from the water and wastewater management sectors within a very brief period of years. Accordingly, the overall institutional knowledge, experience and memory will start to decline steadily which will not be possible to replace immediately by younger and newer recruits. This loss has already been identified as a serious issue for the water sector by the concerned ministry in Japan. Such concerns are likely to become more widespread all over the world in the coming decades.

Fourth, throughout history, cities have had to expand water supply and wastewater treatment continuously because of increasing populations and economic activities. However, in countries such as Japan and South Korea, where populations are declining, the water supply and sewerage systems are becoming progressively much larger than necessary. At present, there is no idea as to how to downsize water supply and sewage collection and treatment systems progressively. Furthermore, as the city populations decrease, ways must be found to ensure viable and sustainable financial models for water utilities that can serve a progressively lower size of population. No serious research is now being conducted on how to downsize successfully urban water supply systems.

Fifth, it is generally the younger people who migrate to urban areas in search of better standard of living. Thus, the percentage of young people in rural areas and smaller towns is likely to decline, with attendant deterioration in economic, social and cultural activities. This could accelerate the breakdown of centuries-old extended family systems where younger generations took care of the elderly relatives. Consequently, the family support system that had existed for generations may start to decline steadily. This may contribute to additional social and economic problems, especially in terms of a deteriorating quality of life of the elderly.

1.3.2 Urbanisation

The water profession has been giving considerable attention to urbanisation-related issues. However, like population, this focus has been almost exclusively on concerns and issues of the past and present and not on the likely problems that different countries are likely to face in the future. Like the issues noted on ageing, the future problems are likely to be of very different nature.

Much of the global attention in the water area has been on megacities, that is urban agglomerations that house more than 10 million people. It is a fact that the highest percentages of the global population do not live in megacities. Rather they will live in medium to small-sized cities where provision of all types of services, including water and wastewater management, construction and maintenance of infrastructure and appropriate levels of investments will be some of the major challenges of the post-2020 world. The population growth rates in these smaller urban centres during 1975–2015 have been about four times higher than in the megacities.

Unfortunately, these smaller urban centres have not been on the radar of most national and international institutions and policymakers. This is despite the fact that their growth rates have been significantly higher than the megacities. These smaller urban centres will find it significantly more difficult to solve their water and wastewater problems compared to megacities.

This is because all megacities have significant political and economic power. Important politicians and business people live in megacities. The bases of major media companies are in megacities. They have access to the lion's share of available national investments, as well as to significant technical, management and administrative expertise. The legislatures of countries or states are located mostly in major urban centres. Thus, the megacities may have problems in the future but somehow, they will manage to bumble along. Smaller urban centres, without adequate political power, financial wherewithal and lower levels of technical and management expertise, will find it very difficult to manage their water and wastewater problems, magnitudes and complexities, which are likely to be significantly higher that their much larger counterparts. Thus, unless these smaller urban centres receive notably higher levels of attention from the policymakers compared to what has been witnessed in recent years, they are likely to become black holes for water and wastewater management.

An important issue that is often raised is how developed countries managed to handle their urbanisation process much better than the third-world countries. There are several reasons for this seeming anomaly. First, the magnitudes and rates of

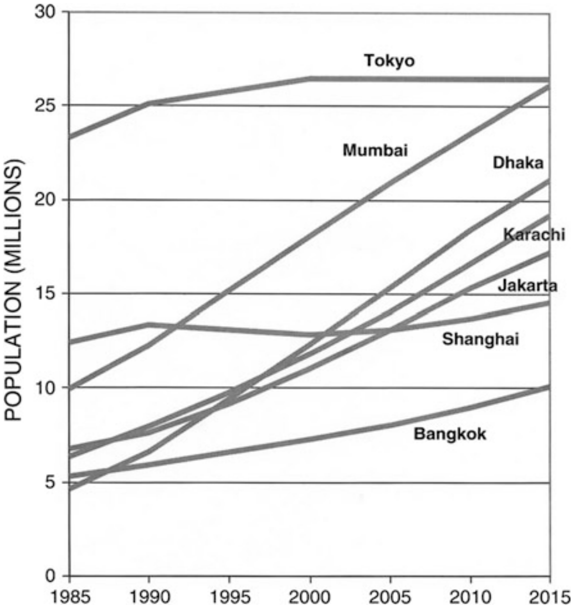

Fig. 1.2 Population increase in selected Asian megacities. *Source* Biswas and Tortajada (2009)

urbanisation that the developed world faced in the past were much less than their counterparts in developing countries are facing at present. Cities such as London and New York urbanised progressively over nearly a century (Fig. 1.2). Their gradual growth rates, economic conditions and management and technical expertise available enabled them to develop and manage their water and wastewater services effectively over a longer period of time. In contrast, the growth rates of Dhaka, Jakarta or Mumbai in recent decades have been explosive (Fig. 1.2). These later urbanising cities have been simply unable to cope with this explosive growth rates in terms of providing satisfactory drinking water and wastewater management services (Biswas and Tortajada 2009). They are finding it very difficult to run faster just to stay in the same place.

1.4 Concluding Remarks

There is no question that rapidly changing global conditions will make future water and wastewater management exceedingly more complex than it has ever been in human history. Interrelated and changing drivers such as population (number and structure), urbanisation, industrialisation, economic development, growth of the global middle class and their increasing aspirations for a better standard and quality of life, and changing societal attitudes and perceptions will make good water and wastewater management progressively more complex and difficult to achieve. Issues such as climate change will add extra levels of uncertainties and complexities.

Continued mismanagement and poor governance practices throughout the world, spanning several decades, have meant that future water security for humankind is now at a crossroads. Extensive policy and market failures in the water sector have received limited corrective actions from the concerned institutions in the past. The net result has been misuse and overexploitation of water all over the world, though in some places less but in others more.

There is now an urgent need to formulate and implement future-oriented, business-unusual water policies and strategies that can reform and strengthen public institutions, manage properly urban and rural environments, increase public and private sector investments, encourage prompt adoption of available and forthcoming new technologies, consider good management practices irrespective of where they originate, and develop a new generation of capable managers and experts from different disciplines and sectors with good communication skills.

Historically, water management policies and plans have been mostly framed narrowly on a sectoral basis with very limited consideration of future drivers from other sectors that are likely to affect water. Very seldom have water managers considered changing societal attitudes and perceptions to water-related issues as has been noted in the earlier part of the present chapter. There continues to be emphasis on short-term fashionable solutions such as IWRM and IRBM, which are extremely unlikely to provide the acceptable long-term sustainable policies and solutions for the new generation of water challenges. Future water problems cannot be solved by using past paradigms and experiences that are becoming progressively infective.

All the major challenges facing the world are becoming increasingly complex and interconnected. The dynamics of human future will not be determined by any single issue but by the constant interactions among a multitude of issues. Increasing population, urbanisation, industrialisation, globalisation and human aspirations will require more economic and equitable development and improved management of natural resources. Ensuring food, energy and environmental securities will require better and continually improving water governance over the long term. The common requirements for all the realistic solutions must include greater and efficient investments, use of more knowledge, technology and expertise from all disciplines, functional institutions and legal systems, and intensified cooperation between countries.

The interrelationships among these issues are global in character. Accordingly, they are likely to be best understood and appreciated within a global framework. While the interrelationships may be global in character, within this there must be a wide variety of efficient and coordinated national and local responses. Water-related problems of the future need to be viewed, analysed and resolved within global, regional and national frameworks. This will be a radical departure from the current practice and will not be an easy task.

During the coming uncertain and turbulent decades, policymakers will have to juggle continuously with competing, conflicting and changing water needs for different purposes by disparate users and stakeholders, as well as concurrently assuring water, energy, food and environmental securities to maximise human welfare. Water will be one of the important threads that will bind all the major development concerns of the future.

There is already a revolution taking place in water management, even though most institutions and professionals are not aware of it. In the wake of this accelerating revolution, long-held and popular concepts and models are likely to evolve further or even disappear completely. Never before in human history has the water profession faced so many profound changes within such a short period of time, as are likely during the next 2–3 decades. The water profession will do well to heed the advice of the eighteenth century British statesman and philosopher Edmund Burke, ‘Never plan the future by the past’.

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Chapter 2
Water: A Megatrends Perspective

Philippe Rohner

Abstract Efforts aimed at equitably and sustainably allocating water to avoid local imbalances between supply and demand and thus longer term resource scarcity, too often focus on technical approaches to increase supply. Technical approaches, by nature, tend to ignore the challenge of incorporating the advances in social sciences to deal with the realities legacy agreements such as water allocation rights or other institutional frameworks such as price subsidies that impede an equitable and sustainable allocation of water. Historical approaches have largely tended to ignore concepts developed from within the economic and social sciences. The objectives of this contribution are thus twofold. First, to discuss the concepts the led to the development of thinking about the long-term and second, identifying those societal trends along with their drivers and enablers that are impacting demand for water given that both, in absolute and per capita basis, demand is likely to continue to grow. Leading from the analysis is the conclusion that water resources need to be viewed both as a public good (asset) and as an economic good (resource) and managed according. Furthermore, demand management is essential to achieve an equitable and sustainable resource allocation; addressing the supply side alone is unlikely to suffice in a growth in demand scenario. The chapter closes by suggesting that practitioners need to address the 'willingness to pay' for water and related services given that it is both a public and economic good. Furthermore, they should consider and encourage the codification of different water standards by first addressing its associated 'value-in-use'. Only then is there the potential of having 'pricing' mechanisms functioning effectively in allocating water in an equitable and sustainable way.

Keywords Water · Trends · Drivers & enablers

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2.1 Introduction

Humans have been aware that managing water infrastructure in urban settings is paramount to their existence not to mention wellbeing (Tortajada 2014). This is evidenced by the prominence of water in ancient texts and the unique role water plays in holy text of all monotheistic religions. Whilst technical approaches have been employed since antiquity to assure sufficient supply is available by searching for new water sources to satisfy an increasing demand for water, a holistic approach, which includes water demand management that incorporate the economic, social and environmental aspects is often overlooked (Koutsoyiannis et al. 2008; Angelakis et al. 2005). While there are examples of societies that have done so successfully for hundreds of years, in many cases water sources have been depleted creating scarcity, which is the ultimate cost borne of failed stewardship of a public good.

As a natural resource, water is unique. From a biological perspective, it both enables life whilst as a transmitter of illnesses, deceases and plaques it enables death particularly among the most vulnerable, namely, infants and the elderly. Access to water, like food and air, is critical for our wellbeing if not existence. Whilst the earth's gravity assures that the atmosphere and that air is equitably available in a natural way, the very nature of water sources, like food staples, requires some form of economic rationale to assure an allocation mechanism that avoids imbalances in supply and demand equilibrium. Whilst access to water as opposed to water sources is regarded as a basic human right, assuring its equitable allocation requires a human-inspired allocation mechanism that recognises the rights and duties of the various stakeholders, all while assuring equilibrium between economic and ecological objectives. From an economics perspective, water differs from other commodities in that it is not the highest bidder that sets the price for the remaining stakeholders. Given these contradictory and conflicting dimensions, societies often struggle to establish mechanisms on how and to what extent to best allocate the water in a sustainable way.

There has been a near total failure to invest in the future of vital infrastructure and how to go about managing water and sanitation needs in urban areas. A focus on how decisions taken today and how they could impact on a longer term horizon is a key step to provide a better understanding of the alternative paths civil society must choose today. Efforts aimed at equitably and sustainably allocating water to avoid imbalances between supply and demand have perhaps in the past focused too often on technical methods for increasing supply rather than seeking innovative ways for how to influence the demand side. Humanists, anthropologists, economists and other social scientists have great understanding of human behaviour. A megatrend view of water could provide a framework that allows them to contribute towards how best to understand the demand side of water use.

2.2 Living in the Futures

Very little is known about the future, but starting in the 1950s the US government, driven in part by the Cold War, collectively started planning for the future and, as a society, began to think about long-term technological change. Forecasting became institutionalised most notably in organisations such as the RAND Corporation and SRI International. Their aim was on understanding the impact of longer term projections most notably on global politics, weaponry and technology. With the end of the Cold War, the use of conceptual frameworks to think systematically about the future lost some of its allure at governmental level as partisan politics and the view that '*if it isn't broke, don't fix it*' policies took on centre stage.

A self-trained social science scholar and freelance magazine writer, Alvin Toffler, more than 40 years ago spent five years studying the underlying causes of a cultural upheaval in the 1960s that was overtaking the developed countries. His research led to 'Future Shock', which sold millions of copies and was translated into dozens of languages (Toffler 1970). He concluded that the convergence of science, capital and communications was producing such swift change that it was creating an entirely new type of society. He reportedly noted that, "*unless intelligent steps are taken to combat the dizzying disorientation brought on by a premature arrival of the future, millions of human beings will find themselves increasingly disoriented, progressively incompetent to deal rationally with their environments.*" (Farhad 2016).

In 1965, Royal Dutch Shell's, Jimmy Davidson, the head of economics and planning for Shell's exploration and production division, together with Ted Newland, a company veteran, initiated long-term outlooks in the form of alternative futures or the practice of scenario planning. Named the '*Futures*' initiative, is still ongoing today as a planning tool for engaging with an uncertain future (Wilkinson and Kupers 2013). This qualitative approach was largely a response to the dissatisfaction with numerical model-based computer projections that are unable to harness the narrative of intuition and experience. Futures studies thus provide a means to focus on plausible and not probable outcomes and seek to balance between the relevant and the challenging by being open-minded and questioning the consensus views. The practice of scenario planning can never identify all forces at play nor can it predict the future. Instead, it provides the plausibility of what the future might hold bearing in mind the need the balance between the relevant and the challenging, which can often go unheard.

2.3 Origins of Megatrends

One potential consequence of living in a hyper-connected world is that, for the first time in history, complex decisions that impact the public and/or consumers at large need to take into account of how the media sets the agenda and often selects those issues that help promote their trade by leveraging ideologies that relate to everyday experiences. Issues that can or are shaping our society at large generally require considerations that are beyond the immediate and outside the scope of everyday experiences. Be it the perception or due to the fact that in a hyper-interconnected world, today, there seems to be consensus that decisions face greater risk (uncertainty) than in the past. This helps explain in part the increased need for conceptual frameworks for reconciling complex and competing interrelationships and in accessing their societal, environment or economic impact.

John Naisbitt, an American author and public speaker, popularised a conceptual framework with which to systematically view outcomes of possible futures with his book '*Megatrends*', published in 1982 (Naisbitt 1982). Based on the analysis of more than two million articles from local papers over a period of more than 10 years of research, 10 major trends (megatrends) were identified not as an intellectual abstraction but as an economic reality. He defined '*Megatrends*' as large social, economic, political and technological changes that may influence society for a significant time—between seven and 10 years, or longer. The book was on the New York Times bestseller list for two years, mostly as number one. This book was published in 57 countries and sold more than 14 million copies (Lewis 1983).

Shortly after its appearance, academics were quick to note that the concept of megatrends could only be understood within the context of an 'irreversible-stage-of-growth' biological metaphor and that state theorists, like Naisbitt, viewed his megatrends as mutually exclusive, viewed the growth stages as mutually exclusive entities and thus concluded that megatrends are "*conceptually indefensible and statistically unreliable.*" (Goldman 1983). Robert Nisbet in '*Social Change and History*' argues that the trend is not amenable to the systematic needs of social theory and is, after all, the early stage of a later development that implies a cluster of identifiable phenomena that has its own internal logic, i.e. an '*entelechy*' guiding its growth (Nisbet 1969).

The purpose observing ongoing and fundamental societal change via trends over an extended period is not about predicting their future course or impact but to diagnose or understand them. Von Groddeck and Schwarz argue that megatrends are completely different from trends, lasting longer, having stronger influence and thus being less predictable, which can only be a retrospective label more appropriate to issues than to trends (Von Groddeck and Schwarz 2013). Megatrends thus differ fundamentally from trends, which often are associated with fashion, which have little if no fundamental longer lasting impact on society as a whole. It remains open to debate if these are megatrends that influence values or if the values that are at the origin of megatrends. Megatrends can thus only emerge in a given region of the world or where the cultural context enables them to emerge. They can create paradoxes, due not only to overlap but that also contradict each other. A megatrend thus impacts the lens with which society views the world, thus influencing values and thinking.

In order to be useful to help understand complex issues, concepts such as megatrends and trends have been found to be useful to communicate the choices as illustrated by a US National Intelligence Council report that notes that 'trends' does not necessarily only imply continuity, suggesting instead that trends can experience "*... likelihood of significant shocks and discontinuities, flirts with a radical revision of any viewpoint*" (National Intelligence Council 2012). The European Environment Agency (EEA) undertook an extended analysis complementing the state and outlook environmental report (SOER) 2015 'Assessment of global megatrends' (EEA 2015).

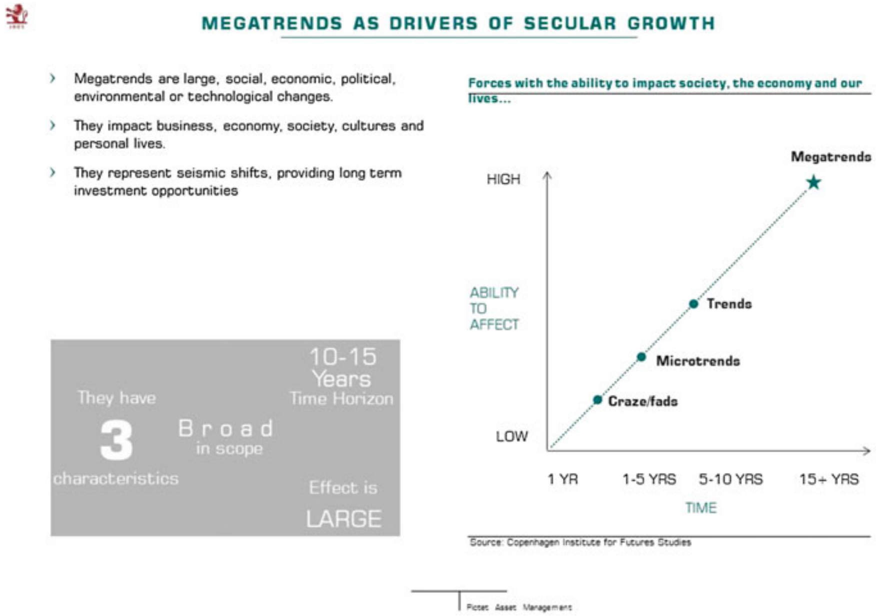
An article entitled, '*The 10 trends you have to watch*' exemplifies how concepts linked to trends are increasingly being used by consulting groups such as McKinsey to assist business executives with articulating business strategy (Beinhocker et al. 2009). Academics are also venturing into the use of these concepts in fields such as Ecological Engineering (Day et al. 2014). Frost & Sullivan, a global consultant house, identified 10 megatrends and have published a series of papers on the outlook of industries and regions (Frost & Sullivan 2010). It grouped megatrends into 4 categories: Urbanisation, Social, Economy and Technology. It notes megatrends as being '*global, sustained and by macroeconomic forces that impact business, economy, society, culture and personal lives thereby defining our future world and its increasing pace of change*'. It further notes that, '*… megatrends have diverse meanings and impacts for different industries, companies and individuals. Analysis of these megatrends and their implications forms an important component of a company's future strategy, development and innovation process, and impacts product and technology planning*'.

Continental Group, the tyre company, utilised the megatrend concept to communicate their business strategy to investors, noting four megatrends that are most relevant to the automotive industry namely, environment (clean power), information (always on), safety (vision zero) and affordable cars (mobility for everyone). Swisscom, defined 10 megatrends impacting life and business fundamentally namely, knowledge culture, customisation, demographic shift, mobility, tomorrow's workplace, networking and digitalisation, globalisation, sustainability and urbanisation. Uponor, a leader in radiant heating and cooling and plumbing, published its Yearbook 2012 using megatrends. Entitled 'Megatrends are shaping the future of building' it provided a glimpse into the future—the current year and beyond, with the aim to look further than short-term quarterly or annual performance, and to focus on businesses and business drivers that impact its performance in the longer term.

2.4 Copenhagen Institute of Future Studies (CIFS)

CIFS is a private non-profit organisation, founded in 1970 by former Organisation for Economic Cooperation and Development (OECD) Secretary-General, Thorkil Kristensen. The staff constitutes a cross-disciplinary group from the natural and social sciences. It regularly updates analysis on different trends and how these are developing or emerging (CIFS 2013).

CIFS regards megatrends as synthetic, complex aggregations of trends—pathways of development—that help make sense of complexity of the surrounding world and take action. These interactions are important individually and can thus be viewed as a starting point for how society is viewed. They form knowledge about probable futures and would include, for example, prosperity and ageing, wherein lies significant insight about the future.



MEGATRENDS AS DRIVERS OF SECULAR GROWTH

- Megatrends are large, social, economic, political, environmental or technological changes.
- They impact business, economy, society, cultures and personal lives.
- They represent seismic shifts, providing long term investment opportunities

They have 3 characteristics
10-15 Years Time Horizon
Broad in scope
Effect is LARGE

Forces with the ability to impact society, the economy and our lives...

Source: Copenhagen Institute for Futures Studies

Pictet Asset Management

At the opposite end are fads/crazes, ‘issues’, which are often mistaken for trends as they tend to be accentuated by the general media and are characterised by their lightning fast appearance and, likewise, swift departure from public awareness. On their own or in combination and over time, patterns may emerge that in turn transform into trends, which are defined at CIFS as ‘*observed pathway of development which have some momentum in a particular direction and some level of durability*’. Microtrends, are a subset of such trends, as they are similar to trends ‘observed developments’, but in an aggregation of a ‘value community’ and in a particular segment with common needs and preferences. Typical examples of microtrends are to be found in goods in the consumer staples category. The aggregation of trends that make up a megatrend are defined as ‘subtrends’.

Megatrends, as noted earlier, are synthetic constructs, a ‘complex aggregation’ of trends, whose purpose is to make sense of the complexity of our surroundings. There is divergence of opinions over the direction of causality and relationship between subtrends and megatrends. However, it is understood that megatrends encompass great forces in societal development that will affect all areas—state, civil society as well as impact the economy and our personal lives—for many years to come (Larsen 2011). CIFS provided for a societal taxonomy with which to view trends as opposed to issues on the one hand, whilst assuring that their evolution would be monitored.

2.5 Megatrends and Water

Facilitated by CIFS, a panel of water industry experts met with the objective of viewing water through the CIFS megatrend perspective. Following a brain-storming exercise, of the 14 CIFS megatrends, six of these were transformed into observed pathways for development, defined as a sequence of events or observed phenomena that have some momentum in a particular direction and some level of durability. For each, we identified the drivers and enablers/bottlenecks.

(1) Demographic Development

Globally, one observes a reversal of the population pyramid, with older age groups becoming larger than the younger ones. The median age of OECD populations will approach 43.8 years of age by 2020. This trend is fuelled by two factors: increasing life expectancy and decreasing fertility. The ageing trend is particularly pronounced in the western world (including Japan), but it is also spreading to the developing countries. In general, a nation's population can grow even if the fertility rate is below the subsistence level of 2.1, if immigration supplements the population, or if life expectancy increases or has increased within a generation. In the mid- to late twentieth century, population growth was seen as a major problem. Today, there is more worry about ageing and a future lack of labour. The average age of the world's population was 24 in 1950 and 28 in 2005—but by 2050 it is expected to increase to 38 (47 in Europe). Almost 10% of the population in developed countries was born in a different country, and migration is expected to increase in the future in spite of some resistance.

A related trend is urbanisation. In 2007, for the first time, the number of people worldwide living in cities exceeded the number not living in cities. Developing countries will experience increasing urbanisation, while the trend will be moderate in Western Europe. The United Nations (UN) predicts that the share of the world population living in urban areas will rise to 54% in 2030. While the annual average rate of change in urbanisation is less than 1% in developed economies and in notable places such as Brazil where a large part of the population live in urban surrounds, the remainder of the world the population shift towards cities is more than double that rate. Urbanisation as linked to the Demographic Development megatrend emerged as the key driver impacting all three value chains associated to water demand namely, the municipal, the industrial and agriculture markets.

(2) Economic Growth

Taken over time, economic growth is one of the most certain megatrends. In the twentieth century, most western nations experienced average annual economic growth rates of about 2%, and their growth rates over the next quarter century are expected to be 1.5–2% annually, although recessions, climate disasters and wars may slow or even reverse such economic growth in shorter intervals (as seen with the financial crisis in 2008–2010). India and China have experienced very high growth rates over the last decade, and though their economic growth is expected to slow down, it will most likely remain higher than that of the West for decades to come, perhaps at 6%. Africa and the Middle East are expected to have similar growth rates because of rising prices of oil and raw materials.

The demographic movement from rural to urban areas enables societies to prosper and thus individuals to undertake higher value-added tasks and thus grow wealthier. The historic association between economic development and urbanisation is well established in that cities are crucial environments and institutional ‘assemblages’ for economic growth. As Brazil well illustrates, cities in less developed economies experience lower rates of natural population increases than rural areas. However, uncontrolled urbanisation poses a fundamental challenge to develop timely and adequate water-sanitation infrastructure and the maintenance of healthy environments, creating a potential for social and political unrest. As disposable income increases there is greater focus on quality rather than quantity of goods and services. In the western world, a lot of consumer money is spent on luxuries, entertainment and immaterial products. In Asia, we see a rapidly growing middle class that wants the same living standards that western consumers achieved in the second half of the twentieth century. Quality and immaterial values (fair trade, branding and so on.) associated with products become increasingly important factors. The state of public services in general and water (and sanitation) infrastructure are often forgotten in that they are key enablers/detractors to urbanisation and ultimately economic development. Where there is a lag in their development, water resources become depleted and in extreme situations, if the situation is not remedied, end up restraining or even in extreme cases, reversing economic development.

A resulting burgeoning global middle class from economic development will impact demand on natural resources. The challenge remains how to meet global middle-class consumers’ expectations from a resource perspective. According to the UN, by 2035 energy consumption will increase by 50% which will increase the energy sector’s water consumption by 85%. Source: http://www.un.org/waterforlifedecade/water_and_energy.shtml. According to the International Energy Agency as cited by the World Bank, the world’s energy consumption will increase by 35%, which in turn will increase water consumption by 85%. cited in: http://wwtonline.co.uk/news/world-bank-water-is-critical-to-energy-production-#.WdzM0kGxWEc estimates suggest, the world’s energy consumption will increase by 35%, which, in turn, would increase water consumption by 85%. That would imply the need for an annual resource-productivity required to meet future global demand on natural resources, which is doubtful if being currently addressed by policymakers. Mobility is another key enabler for economic development, thus transportation fuels or, in the case of urbanisation, takes the form of electrical power and its importance in managing water infrastructure and resources. China, a rapidly urbanising nation, is planning to build around 450 new coal-fired power stations, burning 1.2 billion tons of coal each year. These stations need to be cooled by water. Half the new coal-fired plants are to be built in areas of high or extremely high water stress. In the case of water, which after use, can be recycled and if collected and treated becomes a renewable resource, this requires infrastructure, natural or manmade. One challenge facing the world over the next 40 years is not whether we can produce sufficient calories for a growing urban population but whether we can produce the types of food that people with rising incomes will want to eat at an affordable price. The price of food is largely a function of the cost of sourcing water, another too often overlooked relationship between water and food.

As noted previously, urbanisation poses a fundamental challenge in potentially being the incubator of social and political unrest. Although, and despite the talk of, 'water wars' across national boundaries is often regarded as media hype, 'water riots', which are essentially about food rather than water, merit more serious attention, given that the 'price' accorded to agriculture water, does impacts food prices and, ultimately, urbanisation, which requires social and political stability to develop. Water security is viewed by some strategists in the form of 'land grabbing' is perhaps more a conspiracy driven phenomenon—private and public stakeholders from South Korea, China, India, Saudi Arabia and Qatar have acquired up to 203 million hectares of land in Africa, Asia and South America. This is re-evaluating the ownership versus accessibility debate—is having access enough? According to the Danish Institute for International Studies, water-related events are 66% cooperative and only 28% conflictual, which suggests that water is not the reason for the 'land grabbing' or the potential source per se of international conflicts.

(3) Sustainability

Health and sustainability are both associated with the environment. It was perhaps the combination of the oil crisis and the 1972 report '*Limits to Growth*' that created a new awareness of the responsibility towards natural resources and the recognition of the resource '*problem*' that grew in light of the growing prosperity following World War II and the '*baby boom*' that ensued. The green wave of the 1980s placed a focus on ecology and sustainability and led to the triple bottom line concept.

The health and the sustainability megatrends both address the quality as opposed to the quantity dimension of water. The link between demand and quality becomes evident. Water is a carrier of disease, and poor sanitation impacts public health especially in densely populated urban areas. Like pollution in general, the inadequate or unreliable delivery of '*safe*' water will ultimately restrain if not reverse urbanisation and thus economic development. Together with the technology development megatrend, it is reasonable to state that trends relevant to water, health and sustainability can be either enablers or detractors in the process of urbanisation. That said, water and sanitation infrastructure underpin economic development and thus urbanisation.

(4) Commercialisation

Commercialisation is connected to economic growth: when we grow richer, we are willing to pay extra for individualised products/services to save time and effort by outsourcing. Commercialisation occurs when considerably more areas in society are made subject to commercial business. This includes not just physical goods and services, but increasingly also immaterial values like culture, opinions, community and politics. Things that used to be free (or nearly free) or do-it-yourself are offered as commercial products and services. Examples are bottled water, fitness and dating. Another factor favouring commercialisation is the breakdown of many old public services. When public schools, hospitals and pensions are seen as insufficient or ineffective, many people become willing to pay for commercial alternatives. Many former public services, such as railways, postal services and eldercare, are also becoming privatised or liberalised, paving the way for greater competition and hence more commercialisation.

The question is what role if any can public sector play in shaping the water challenge. Companies of tomorrow will cooperate through partnerships to reduce waste, increase recycling, and provide networks for water systems operations and management. Commercialisation, in the form of Public Private Partnerships (PPP) has now been part of the water industry with, some would argue, a mixed amount of success. The debate lies ultimately with the sources of finance and degree of subsidies and by whom the public or those that benefit from the services. This is particularly relevant as the infrastructure and operation are very capital intensive and the associated services constitute a natural monopoly. Being an essential good, water itself is seen by some as a public good, a public asset of sorts, whilst others think it should be treated as a resource where the marginal user sets the price for all. The reality probably lies somewhere in between.

(5) Technological Development

Since the beginning of the industrial age, technological development has accelerated, so changes often come faster and in more ways. Technological advances are more than anything a source of change in society. New technology creates opportunities for new business models, provides new ways to handle existing problems and new areas to develop science, which may have a revolutionary effect in the future. The purpose of technology is generally to make life easier and more enjoyable, replacing or easing hard or boring work, provide new opportunities, and make it easier to exchange information and ideas. However, technology can also have negative ‘harmful’ effects, e.g. weapons, computer viruses and recreational drugs or have unintended side effects such as pollution and structural unemployment. Sometimes new technology also gives rise to ethical and moral questions that we may not want to answer (though arguably having the questions asked may be a good thing in itself). The most important technological development areas in the next decades are information technology (digitalisation), biotechnology (genetics) and nanotechnology (material sciences).

There are two key aspects that ultimately impact water: the reducing invested capital and the operating costs of transporting/delivering the treated water to a specific quality standard. The extent to which technology gets developed and adapted is less related to ability and more to willingness to pay by urban dwellers. The economic incentives for approaches that require technological development are perhaps too often stymied by government policies that are too short-term focused.

(6) Health

The World Health Organisation (WHO) has estimated that by 2020, 70% of health sector expenses will be used for treating lifestyle-related disorders. With increased affluence and the automation of hard, physical labour, there has led to an increase in the number of lifestyle-related disorders such as obesity, poor condition, anorexia, over-indulgence in alcohol and so on. As medical technology improves, more diseases and disorders can be treated. It is likely that more people will demand such treatment without regard for its cost. There is no upper limit to this expanded health, hence an increasing fraction of resources are spent on health. If you are not fit, you are considered unhealthy, even though there's nothing physically wrong with you. Being healthy for the modern urbanite is not just a matter of not being sick; rather, health has become a positive concept that includes vitality, energy, balance and being in control of life, mentally as well as physically. Whereas diseases and handicaps can be seen as something out of your control, being unfit is increasingly seen as being your own fault. It has very much become an individual responsibility to eat right, exercise enough and stay mentally fit.

An increasing amount of resources—personal as well as public—is spent on health. There are several reasons for this, most addressed previously under economic development. As we urbanise our disposable income increases, we can afford to focus more on quality rather than quantity. It illustrates that demand management is more about managing quality rather than quantity. Another aspect that the health megatrend brings to light, is the issue of willingness and ability to pay when it comes to our own health, namely that the cost should be borne by society. Whilst there is clear demand that drinking-water be free of micro-pollutants, few are willing to see their water bills increased even though it represents the smallest of the households' total utilities bill.

2.6 Concluding Remarks

That the future is never assured is also true for our water supplies. Whilst megatrends provide us with insight about the future, what is less certain is how organisations, society or individuals react to such '*forces*', given that these get viewed through different lenses and thus reactions to them differ. The analysis using megatrends thus tells us something about a probable future, being aware that there are other possible futures. What is conceptually important is differentiating probable from predictable and preferred futures. A probable future expresses what we know about the future albeit with some elements of uncertainty contained within elements of '*paradoxes/counter-forces*'. Of note, is the temporal dimension that largely determines the potential impact. In other words, fads, like current issues, are, by definition, early stage developments, which are not part of this analysis, but can evolve into trends, which, in turn, when grouped with other trends, aggregate into forces in societal development whose ability to impact are not only material but also probable.

We were able to identify alternative pathways of development that if addressed would reduce the demand on water sources. Water sources should be viewed as both a public asset and as an economic resource and managed accordingly. Water quality varies and should be further codified into a cascade of different qualities to meet specific uses to reduce further demand on water sources. Water productivity requires allocation mechanisms that provide price signals to which users can better match quality and its use for which there are takers willing and able to pay, thus enabling the marginal user as the price setter for the remaining users of a given quality level.

The demands on water sources have risen and continue to rise and increasingly so as larger parts of the world's population become wealthier. Choosing in greater numbers to live in dense urban settings is shaping the probable future of water. Historically, focus has been addressing the supply side of water, aqueducts, re-routing rivers, constructing water dams and so on. On the other hand, productivity of water use is only then addressed when supply alternatives are no longer practical or have been exhausted. Several developments associated with demand management were identified that would need to be enabled in order to equitably allocate water whist preserving current water sources. It is worth noting that popular concepts such as virtual water and that of water footprints were concluded as being a means to increase awareness but not of great use as a decisional tool.

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Chapter 3
Population Megatrends and Water Management

Olli Varis

Abstract Demographic development is a megatrend, which ties to almost any other conceivable megatrend. Comprehension of most significant features of the world's population development is fundamental when elaborating other megatrends. Despite, the concurrent debate on development policies, and future prospects of freshwater management seem to overlook the dynamism and continuous, rapid and location-specific changes in many of the key demographic features as they develop in different parts of the world. This chapter demonstrates some of such features, calling them 'myths', and elaborates the impact of such features on water management. It is recommended to be careful with the use of many common development jargon words (such as 'global south' and 'industrialised country') and to scrutiny the key demographics before entering any debate on megatrends that has a link to demographic development.

Keywords Demographics · Development policies · Water resources management
Urban development · Ageing

3.1 Introduction

One of the certainties with regard to future projections of the planet is that the future will not be similar to what it is now, nor will it follow any extrapolations of the past developments. Anyway, looking at past tendencies and trends can be a useful exercise in order to reflect and scrutinise how they could be different from the past ones in order to enhance developments that are seen positive.

Population growth is undoubtedly one of the most important megatrends of the planet, and it intertwines to most of the other megatrends. Therefore, it is fundamental to understand the essentials of world's population projections in order to elaborate the other megatrends.

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The United Nations (UN) Population Bureau publishes each year an updated projection for the world's population, and every two years an updated projection for urbanisation. The former is done today up to 2100 and the latter up to 2050. The projections are presented by country, as well as by income categories and geographic regions. Some other agencies present their projections, too, such as the International Institute for Applied Systems Analysis (Lutz et al. 2014). It is common to those projections that they include a series of scenarios, which are based on varying estimations of the basic demographic parameters such as fertility, mortality, migrations and so forth.

This paper summarises the most crucial ones among these trends, and links them to societal development of the macroregions of the planet. This is done by challenging five 'myths' or very common conceptions, which, despite being in very common use even in professional contexts, are not entirely correct. Actually, they are increasingly incorrect along with the evolving global population megatrends. Particular focus here will be on the time-period 2030–2050.

For the first three myths, I am using the UN projections and the median projections (UN 2014, 2015). The demographic projections are scrutinised, and some implications to water drawn. The last two myths use more elaborate datasets described in detail in Kummu and Varis (2011). The method will be a combination of an explorative approach and data analysis. A selection of classics in economic literature are used as references.

3.2 Water's Many Societal and Economic Roles and Functions

Before entering the five myths, let us have a look at the various roles and functions that water has in societies and economies, as water has many quite fundamental and quite different facets and functions in them. Therefore, water resources management is by the outset linked to most sectors of the society.

Water intertwines in the everyday life of humans in countless ways. The importance of water as a driver for health, food security and quality of life and as a pillar for economic development is unique. As water affects human lives, mankind also has an effect on the hydrological cycle of the planet, in all dimensions from the very local to the global scale. The production of one kilogram of grain consumes 1000–4000 L of water. Food production accounts for the majority of water use globally. Hydropower production by damming rivers evokes strong emotions; yet sustainable energy production is among the cornerstones of economic development and water has a key role to play. The damage caused by floods and droughts is escalating. The human impact on ecosystems is catastrophic in immeasurable ways. Water is largely a political good since a bulk of humankind lives in river basins shared by two or more nations.

Water is a backbone of the economy in very many countries of the world. Water resources management provides the foundation of the agricultural sector, much of the energy sector, is an important part of the urban infrastructure, healthcare and many other functions of society. Economic growth is desperately needed in the reduction of poverty, but growth alone is not sufficient. Wellbeing must reach the poor, otherwise the growth only polarises the economies.

The role of water is very important in this complex interplay. Besides being fundamental to many economic sectors, water is also a key to meeting many of the basic needs that are, in turn, instrumental in poverty reduction.

(1) Environmental threats: by far the most detrimental environmental catastrophes are floods and droughts. Water is the main carrier of environmental pollutants, inadequate sanitation often being a major cause for pollutants. It is also the major agent in global erosion, desertification, decline in biodiversity and climate change problems.
(2) Traditional societies and the traditional sector: their economy is tied to nature and very closely to the water cycle. The development of water management and sanitation requires culturally tailor-made approaches.
(3) Housing and the informal sector: water and sanitation are key constraints for decent housing and livelihood as well as for the rapidly growing informal sector; the challenges are soaring particularly in urban conditions.
(4) Agriculture: accounts for 70% of all water use by humans. In most developing countries, agriculture accounts for over 90% of all water withdrawals. Water infrastructure and services provided by aquatic ecosystems are backbones of the economy and livelihoods.
(5) Industry: in large parts of the developing world industry is developing more rapidly than ever before. Many industrial sectors rely on water. The challenge of pollution is soaring.
(6) Energy: it is fundamental to understand that 96% of contemporary renewable energy production comes from either biomass or hydropower. These both rely completely on water resources management.
(7) Services: for many service industries such as tourism—which is the fastest growing sector of industry in the world and among the key potentials in many developing countries—water, adequate sanitation and a healthy environment are elementary.
(8) Economic growth: water infrastructure is typically quite capital intensive and short-term economic returns are not very obvious. Nevertheless, as a backbone of economy, the indirect and long-term benefits are massive.

The water sector is typically considered as a sector by itself. However, this sectorial view gives only a very limited appreciation of water because it is also a crucial component in several other sectors as indicated above.

3.3 Myth 1: Population Growth Is Urban

Averaged over the globe, it looks as if rural population would stay almost constant over the coming decades whereas urban population is in steady and fast growth. Thinking that virtually all population growth is urban and that the rural population would be staying roughly unchanged in size is, however, great albeit frequent oversimplification. In several regions, the population follows a quite different pattern, though, and it can be highly misleading to stick on the global pattern in discussing population issues for most of the world's regions.

Figure 3.1 (upper) indicates, indeed, that virtually all population growth ends up in urban areas, and the rural population is expected to stay almost constant or even shrink slightly in coming decades. In 1960, there were roughly two rural citizens per one urban. In 2005, urban and rural population were close to equal. By 2050, urban population is expected to be two times the size of the rural population. Nevertheless, this growth is largely being fed by a far higher fertility rate in rural

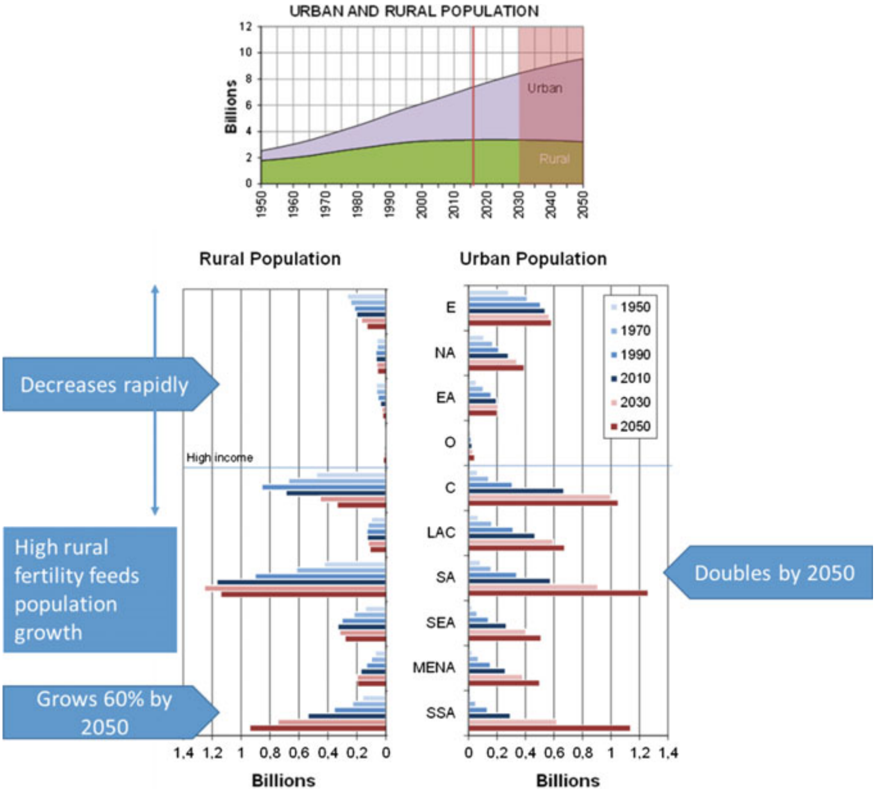

Fig. 3.1 World's urban and rural population by region in 1950–2050. *Data sources* UN (2014, 2015)

than in urban areas, and the continuous and voluminous migration to urban areas lies behind the urban growth.

The development pathways in different parts of the developing world are increasingly diverging from each other (Fig. 3.1). In high-income countries as well as in China, sharp decrease in rural population takes place, and this trend is expected to continue for several decades. Urban population will grow slightly in high-income countries, but will continue to be speedy in China. In Latin America and the Caribbean as well as in South and Southeast Asia, and in Middle East and North Africa, rural population will show modest changes whereas urban population will grow fast—these regions are close to the world's average development. Africa looks quite different from the other regions, as its rapid population growth will swell both rural and urban population quite fast. On average, Africa's urban population is expected to triple and Asia's is expected to double by 2050.

It is notably common that governments, in their search for economic growth, favour urban development. Jobs are urgently needed and consequently sought after, and investments in urban areas are often easier to get than investments to typically capital-intensive and low-productivity primary industry activities in rural areas. However, rural and urban development are best developed hand in hand, and developing economic and social conditions in rural areas are key to reducing fertility. These in turn help in controlling urban growth and balanced social development.

Besides, it is frequent that governments are not keen in even mentioning the problem of informal settlement formation, or slums, in their policy outlines (Varis and Abu-Zeid 2009). Most of the perennially recommended issues such as decentralisation, cost recovery, economic instruments, legislation, private sector involvement, stakeholder participation, adaptation of costly, non-conventional water technologies such as recycling and desalination, and many others have often totally different shades in the informal sector in comparison to how they appear in the formal sector. Addressing the slum problem needs solid and integrated urban and rural development policies.

3.4 Myth 2: Dramatic Ageing of High-Income Countries

When looking at the population from the point of view of economic development potential, one of the basic factors is the share of the economically active population of the whole cohort. Globally, this ratio, known as Potential Support Ratio (PSR) is now 1.9, and it appears to be peaking just now (Fig. 3.2). It was only 1.37 in 1965 due to high percentage of children, and is going down again, but this time primarily due to growing percentage of elderly population. The outline for interpreting the PSR figures from the point of view of economic potential is the following. The higher the PSR, the more development potential the economy possesses. This is simply because with a high PSR, a large part of the population is economically active.

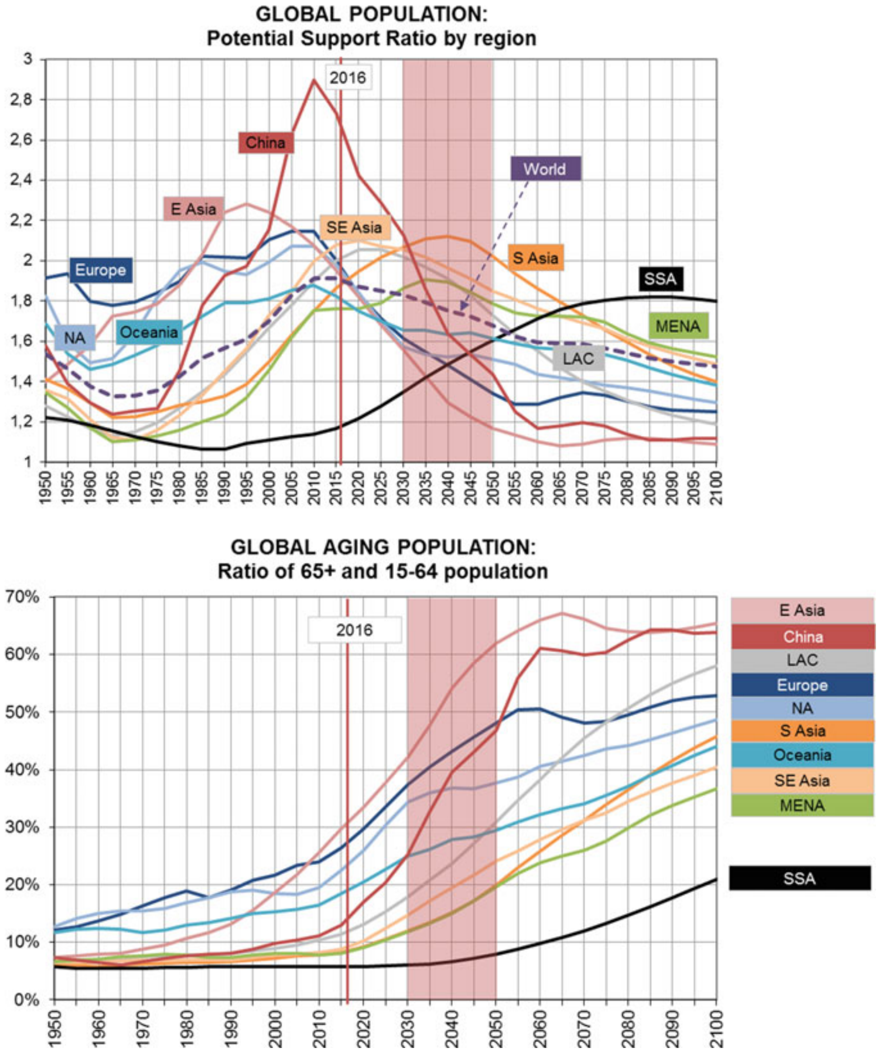

Fig. 3.2 Working-age population and aged population. Upper: potential support ratio by region (ratio of working-age (15–65 years) to other population) Lower: ratio of aged to working-age population. Estimates 1950–2014 and median projections 2015–2050. *LAC* Latin America and the Caribbean, *SA* South Asia, *SEA* Southeast Asia, *MENA* Middle East and North Africa and *SSA* Sub-Saharan Africa. *Data source* UN (2015)

China has been a particular case in terms of PSR. Its PSR has recently been much higher than in any other part of the world; it reached almost 2.9 in the previous decade, but is now dropping rapidly and is expected to halve from that peak level by 2050. In South Asia, the peak will take place around 2040, in the MENA (Middle East and Northern Africa) region somewhat earlier, but in

Sub-Saharan Africa the peak will not be reached until 2085. Sub-Saharan Africa's PSR is currently far below any other region, but it is in gradual increase. It is expected to reach East Asia's level by 2035, Europe's by 2040, and China's in 2045.

It is a common myth these days to think that high-income areas in Japan, Europe and North America are suffering particularly much today and in coming years from the challenges due to an ageing population. Still today, this is not entirely incorrect as the size of the aged (those of 65+ years) population of East Asia, Europe and North America is higher than in other parts of the world (Fig. 3.2). However, by the period 2030–2050, many developing regions will show a dramatic growth in their elderly population. China is the most drastic example as its population has begun to age more rapidly than anywhere else.

Anyway, the shares of high-income areas from the total aged population of the planet is in steady and rapid decline (Fig. 3.3). It is highly illustrative and important to compare the headcounts of elderly populations in high-income regions to those of middle and low-income regions (Fig. 3.4 lower panel). Ageing of the populations of the latter will indeed be a significant economic and social issue for the study period 2030–2050.

As the economically active share of a population decreases in relation to the aged population, the working population must support in one way or another

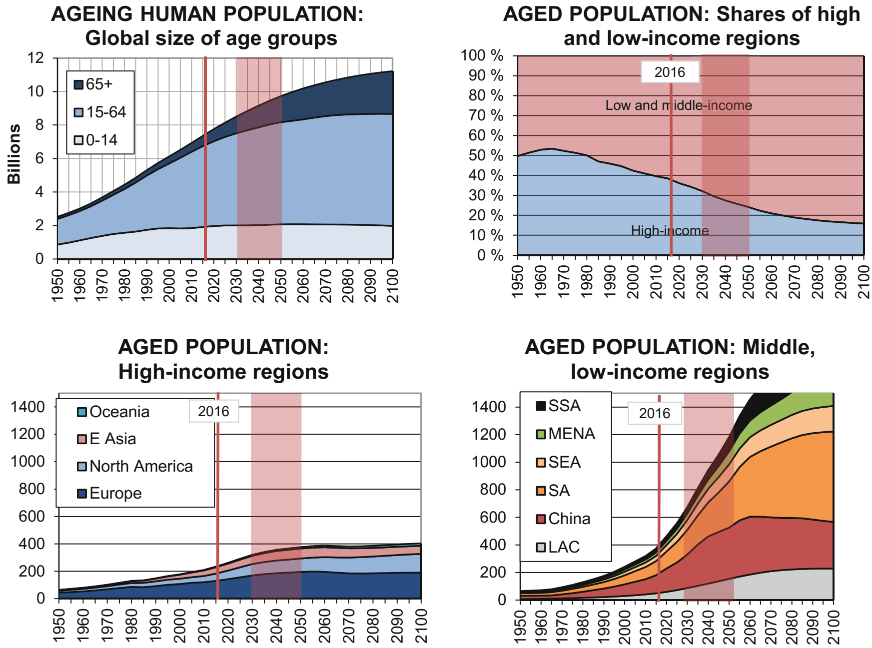

Fig. 3.3 Ageing of world's population: estimates 1950–2014 and median projections 2015–2050. *Data source* UN (2015)

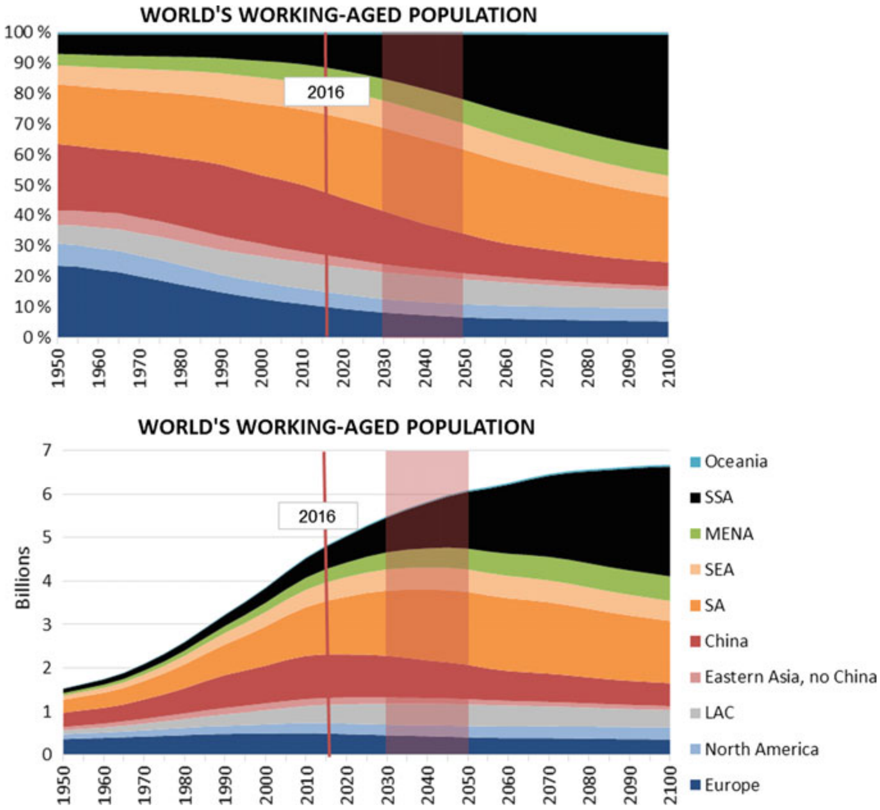

Fig. 3.4 World's working-age population by region in 1960–2100. Acronyms as given in Fig. 3.2 *Data source* UN (2015)

increasing masses of people who are in the elevated need of various social and health services.

In more advanced economies, the percentage of aged population will grow heftily, and employment is in decline. Tax accumulation for the funding of pensions and other services for the aged is already a growing problem, but the challenges will soar rapidly in the coming years and decades. Gross domestic product (GDP) growth will, in most predictions, slow down and the primary source of economic growth will be in the growth of productivity. Water challenges are expected to be related to ageing principally through economic development and ability to be able to provide and maintain degraded water infrastructures particularly in the field of water supply, sewerage systems and wastewater treatment as well as irrigation and drainage. The ageing problem is burning in rural areas where competent labour is scarce and insufficient.

In countries in which the ageing development is modest and urbanisation is not too massive (e.g. Latin America and the Caribbean, China, Southeast Asia) economic development may take place both through growing labour force and growing efficiency. Tax accumulation will be far easier to be kept high than in countries with declining labour force. Relatively low need to ageing-related public spending provides plenty of possibilities, but on the other hand, typically, the countries in these regions have an immense need for infrastructure development.

In regions where the fertility rate is still high and the population growth remains rapid (Africa, West Asia, South Asia, Central Asia), it is critical to economic and social development how the urbanising economy will absorb the huge incoming and typically relatively poorly educated labour force. Investment needs are enormous, and restructuring of the production system would be crucial to economic development, but capacity and typically, political will is insufficient in relation to the development needs.

If economic growth and infrastructure development will not be achieved in the times of favourable PSR, they will become increasingly tough with shrinking of the share of the working-age population in decades to come. All regions except Sub-Saharan Africa are already at the phase of rapid growth of the share of aged versus working-age population (Fig. 3.2).

3.5 Myth 3: World's Working Hands Are in Asia

In recent decades, a bulk of world's economic and social development has occurred in Asia, and it has been commonplace to outsource labour-intensive production to various Asian countries, particularly to the Asia-Pacific Rim. Asian workforce has been in steady and rapid growth over decades, and job creation has been mostly quite successful yielding to fast developing labour market and economy. Consequently, poverty has dropped drastically in those geographic areas.

This situation will change rapidly due to the profoundly different demographic pattern of Africa from Asia and other parts of the world. Figure 3.2 shows that the PSR of Africa is significantly lower than that of any other region of the world, and Fig. 3.1 indicates how rapid Africa's population growth will be in coming decades.

Africa's projected population development will rapidly lead to a situation in which the majority of new jobs on the planet will be needed in Africa, not in Asia any more (Fig. 3.4). Whereas the Asian labour force will remain roughly unchanged in size by 2050, this will not be the case in Africa. The major labour-related issue in Asia will be structural change (Leopold et al. 2016) as the economies ladder up in the value chain.

In the coming 10 years, Africa will have 170 million more people in active working age (15–64 years) than today. The growth will only accelerate after that, and in the subsequent 10 years the net addition to Africa's working age population will be 250 million. Africa's workforce in 2030 (at the time of the reference year of United Nations Sustainable Development Goals) will be 54% higher than in 2015, and grow altogether 2.5 times between 2015 and 2050. By 2050, Africa's labour force will be of the same size as the sum of China's and North America's today.

In fact, the world's job creation issue can be largely condensed to the job creation challenge of Africa. In other regions, the changes in workforce are minor in comparison to that of Africa. The only major change besides African growth by 2050 will be the growth of South Asia's workforce that roughly increases by the same amount as China's decreases.

How will Africa provide jobs for its soaring work force? This is an extremely interesting and fundamentally challenging question, to which there is no simple answer. Some of the major challenges include the following two:

- Industrialisation and capital formation of Africa are currently very low, as will be illustrated within the context of Myth 5 below.
- Capacity of Africa's nations to make development leaps of the society and economy are particularly low.

The latter point can be illustrated by the volume of high-level science (Fig. 3.5): today, Africa produces a mere 0.2% of world's high-level science, whereas Asia produces over one-third (Nature 2016). Africa's level of production of high-level science (in *per capita* terms) is 1/500 of North America's and 1/11 of China's corresponding levels.

The two challenges mentioned above are actually the basic factors of the famous and amply used growth model of Solow (1956), which can be condensed into the

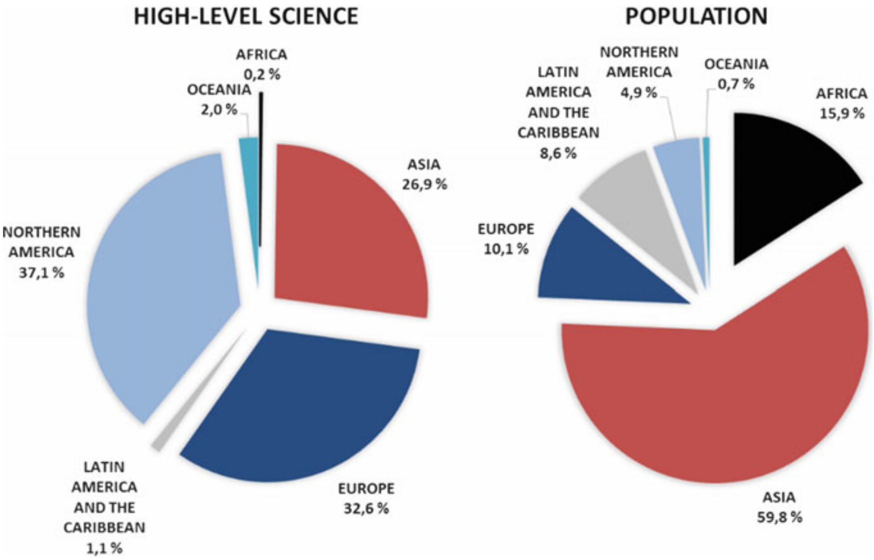

Fig. 3.5 The global disparity between population size and production of high-level science. For high-level science, the WFC (weighted fractional count) index is used, which measures articles in highly ranked journals so that if an article has n authors, each author gets $1/n$ scores for that article. In addition, certain research areas with a practice to publish essentially more papers than other areas are weighted down *Data source* Nature 2016

Table 3.1 Africa's future opportunities and risks

Opportunities	Risks
Rapid and massive education	Massive emigration, exodus
Governance leap	Massive poverty problem and slum formation
Attraction of investment Now goes to primary industries (land, mining, etc.) Possibilities to (1) Secondary (massive demand growth: energy, environment, institutions, infrastructure); (2) Tertiary (massive demand growth: education, communication economic security, infrastructure, etc.)	Challenge to state stability
Local self-employing frugal development	

following equation, which also includes below a conceptual characterisation of selected macroregions of the world *vis-à-vis* its major factors of growth:

$$\text{Growth} = \text{Capital}^{\text{flexibility}} \times \text{labour force} \times (\text{technology\&education})^{1-\text{flexibility}}$$

In a nutshell, in the above equation, capital allows investment, labour force allows volume of production, and technology together with education allows progress and productivity. If we look at Africa, capital is very low and so are technology and education. Only labour force is already large and growing rapidly. If this labour force will not be employed, massive social problems are likely to occur. Instead, in East Asia, capital formation is fast and capital has become easily available. Labour force is large but starting to shrink. Technology and education are growing rapidly and prerequisites for progress are very good.

Consequently, the global concern and attention of job creation should be now and in coming several decades in Africa. Some ways to commence are presented in Table 3.1. If the endeavour of job creation for Africans will not be successful, there will be an unforeseen human catastrophe and/or a massive migration of Africans outside of their continent. Both of these are issues that obviously will change any debate of water sector development to quite different spheres and focal areas from the mainstream future-oriented water discourse of today.

3.6 Myth 4: Global South

Given the fundamental heterogeneity of demographics in different parts of the world—particularly in the areas which are usually called 'developing' countries, I shall now elaborate the terminology that is frequently used to describe these areas covering most of the human population. The terms chosen are revealing, although many more terms of similar, imprecise, use could be taken as examples.

The expression ‘the South’ or increasingly ‘the Global South’ has become synonymous to nations often called developing countries. The most important proponent of the use of the cardinal directions south and north in this context was the so-called (Willy) Brandt Commission Report (Brandt 1980), and the concept has become popular during recent decades. This approach has obviously been thought to be less value-laden, being also a more romantic one than ‘developing countries’, or not to talk about the formerly used term ‘less developed countries’.

The term has a political and ideological origin, and it gave the name to movements such as the South Commission that was launched in 1987 to represent ‘Third World countries’ and unallied countries in various settings. Accordingly, the term ‘the North’ is used in this metaphor to mean high-income countries, or developed countries. The divide between the North and the South has conventionally been considered to be around the latitude 30°N, as defined in the Brandt Report.

The use of this metaphor draws from the idea that the wealthy nations tend to be located in northern parts of the globe, whereas the less affluent ones lie on their southern edge. Looking from the perspective of the USA or Canada, this is a natural conception, since the countries that are located southwards have distinctly lower economic development level in comparison to those two countries. The same holds also for the most of Europe, particularly its western and central parts. Looking southwards from there, Africa and most of Middle Eastern countries are less economically advanced than most of Europe. In Asia, the pattern is not as clear as in the Americas or in Europe, yet many of the economic powerhouses, particularly Japan and the Republic of Korea are located further north than most of the Asian population.

The use of the Global South vocabulary has spread to various academic disciplines but it has become particularly popular in organisations such as the UN and other donor-related institutions (Taylor et al. 2009). There has been some criticism to the vocabulary due to its obvious ambiguity; as Wolfgang Sachs points out (Alloo 2007), the countries of the South are most heterogeneous, ranging from Singapore to Mali with not many common nominators. He calls the vocabulary as ‘obscure’ as being used without clear definitions and forgetting that social contrasts within countries are often more striking than between countries.

We wanted to investigate how the world’s population is, as well as the development levels of different nations are divided across the north-south axis of the planet (Kummu and Varis 2011). Astonishingly, we found no analysis on this obvious topic. We wanted also to know, whether there is a clearly distinguishable north-south division around the 30°N latitude, and, consequently, whether the Global South metaphor is geographically valid. This was achieved by looking at global, high-resolution geographic databases on the temporal development of the human population during the past half century, and relating those to nation-specific data on the evolution of selected economic and social development indicators.

We used an array of development indicators for this purpose (Fig. 3.6). The northern hemisphere includes 87.5% of the world’s population, with an average GDP *per capita* of US$9310. The geographic south of the globe, if we define it as including the areas south of the equator, constitutes thus a minority of the world’s

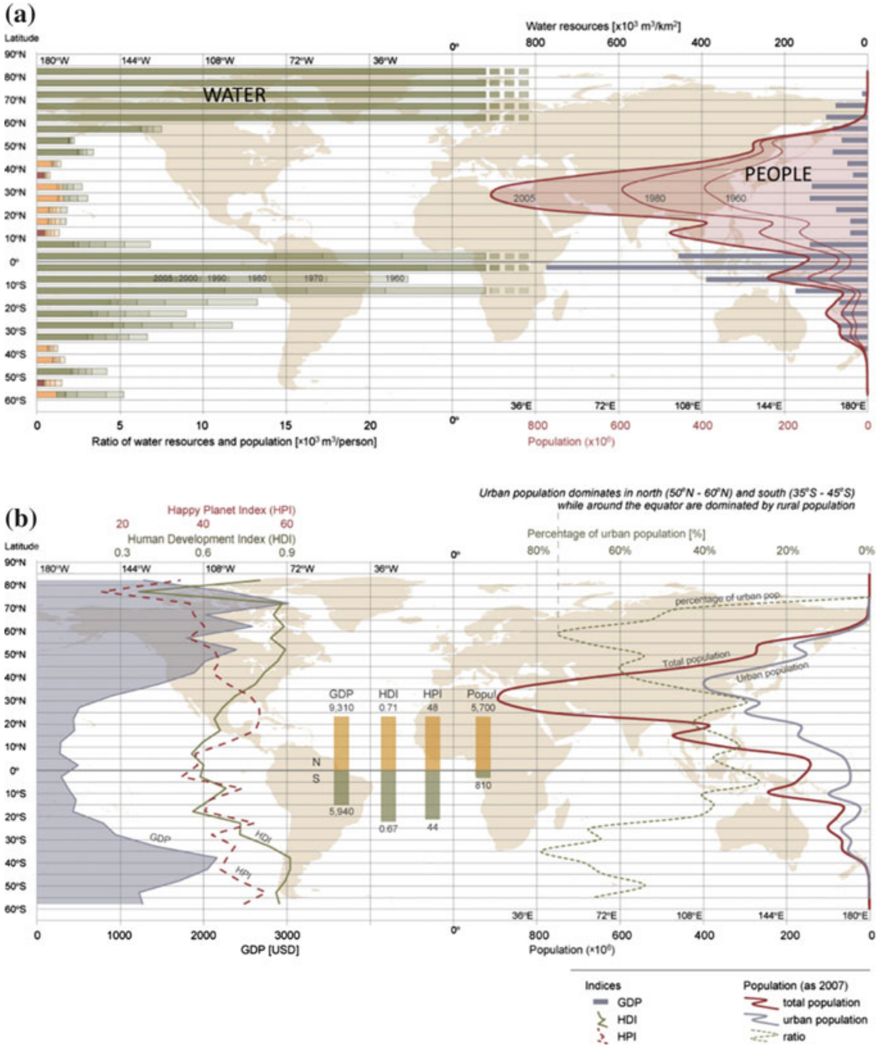

Fig. 3.6 **a** Latitudinal distribution of population and renewable water resources (adapted from Kummu and Varis 2011). **b** Latitudinal distribution of rural and urban population as well as five commonly used development indicators (adapted from Kummu and Varis 2011)

population as only one person out of eight lives there. The average GDP *per capita* in the southern hemisphere is US$5950.

The south has thus a somewhat lower income level than the north. Yet, in the global view, much more important is to understand, that the latitudes around the equator exhibit remarkably low-income levels, whereas both in the north and in the south, the income levels are significantly higher. Thus, a clear accumulation of low economic and social development can be detected from both sides of the equator, roughly between 20°S and 20°N, according to some indicators up to 30°N. Pressure evoked by the humankind to natural resources such as water is most pressing between 10°N and 50°N.

There is a remarkable concentration of the planet's people between the latitudes 5°N and 50°N, and, in particular, 20°N and 40°N. The economic and social development level on this part of the world is subject to high variation. Whereas this area includes some of the most affluent societies of the world, it also includes a remarkable concentration of poverty. We estimated that 50% of the world's population live within the area between 20°N and 40°N. 58% of them live in low and low-middle income countries. Many of these countries are today somewhere between the traditional understanding of a developed or developing nation. China is a good example, which is not easy to classify along this axis, and is not even needed —the jargon is simply not valid, useful nor correct, as shown in the next section.

3.7 Myth 5: An Industrialised Country

China could serve as an entry point to a scrutiny of many other jargon words—a further example could be 'an industrial country'. China is far more industrial than most of the countries that tend to be called 'industrialised countries' in the development jargon. In China, industry's share of GDP is double the OECD average, and the share is similar for instance to that of Lesotho or Thailand and many other 'non-industrialised countries'—in fact, they are far more industrial than OECD countries (in which typically services override clearly the industrial output's share in national accounts).

Nevertheless, the term 'industrialised country' is used quite commonly synonymously with high-income countries. This usage of terms is quite astonishing, since evidently most people learn already at school that it is typical of high-income countries that their gross national income (GNI) arises dominantly from services. At the level of macroeconomic theory, the concept of structural transformation goes back to the work of Clark (1940). He observed already at that time that industrialisation (secondary activities) tends to dominate at a relatively early phase of economic progress, and is a transitional phase to post-industrial (tertiary) society.

In this society, services and knowledge-intensive jobs dominate (Fig. 3.7). However, even top-level political meetings pair the concept of the industrialised and developing countries together, the former meaning obviously high-income countries and the latter merely middle and low-income countries.

Today, where are the world's most industrialised countries? Using the manufacturing industry's GDP share as the criterion, the most industrialised countries can be found from the Asian continent, most specifically from the region called by World Bank 'the Developing East Asia' (Fig. 3.8), which according to world development indicators (WDI) (2016) includes countries from Mongolia and China, across Southeast Asia to the Pacific Island Small States. In that region, the share of manufacturing industry has remained over 30% of GDP over several decades, and

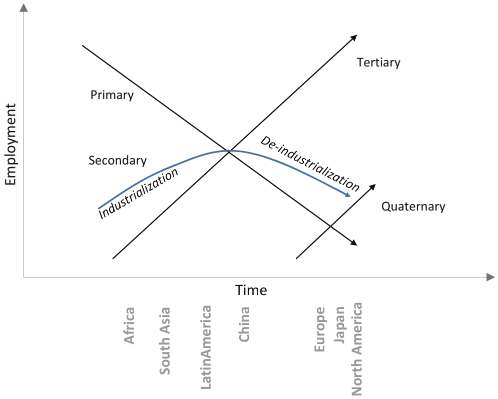

Fig. 3.7 The economic sector development model, developed according to the idea of Clark (1940). The sketchy positions of the regions are by the author

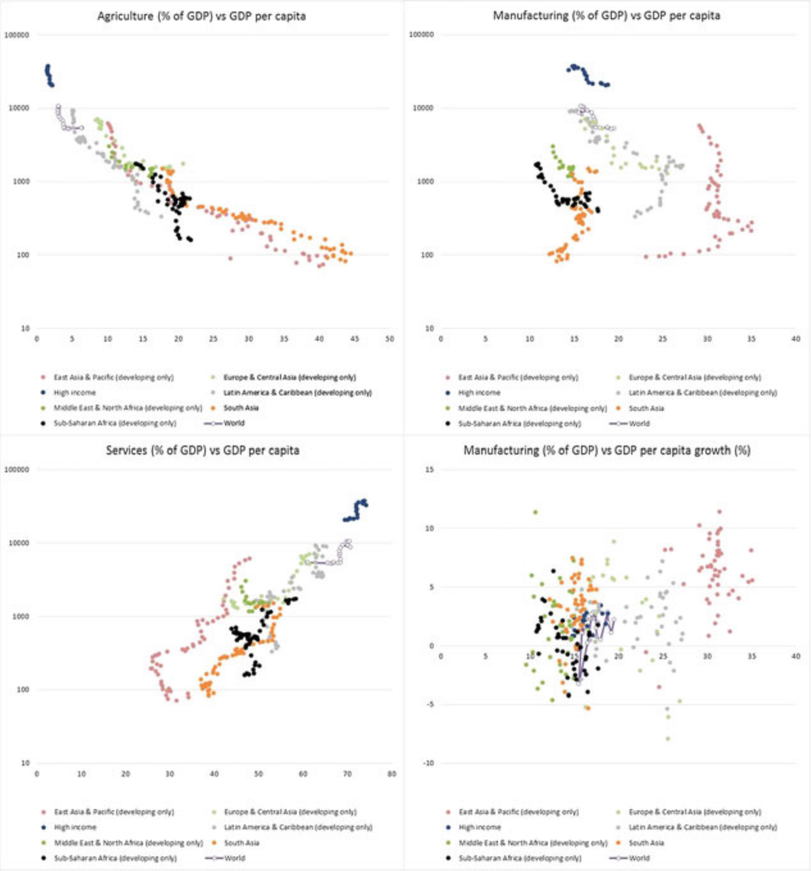

Fig. 3.8 Structure of economy and GDP in the macroregions of the world. Evolution from 1960 (low GDP) to 2015 (high GDP) (data source WDI 2016).

is presently far above the level of any other region (not all countries are industrialised but the regional average is higher than that of any other region, and some large countries, most importantly China, dominate the averages). In high-income countries, the share is now below 15%. In Latin America and the Caribbean as well as in South Asia, the industrialisation level is roughly same as in high-income countries. The lowest industrialisation levels are found in Africa and in the Middle East.

Rather than with income level, industrialisation has a stronger correlation with economic growth and still more remarkably with capital formation. East Asia and Pacific has, these days, the world's strongest formation of capital, whereas the least industrialised countries in Africa and Middle East have the lowest ones (WDI 2016).

The different development phases or 'sectors' (primary, secondary, tertiary, quaternary) have fundamentally different needs and impacts on most aspects of the society, natural resources and the environment (Fourastié 1949). Whereas the primary activities (such as agriculture, mines, etc.) rely on the large consumption of land, water and other physical resources, their knowledge intensity is low and technological level too. The secondary activities are thirsty for mechanical machinery, manufacturing technology, energy; raw materials, etc. and pollution problems are substantial. Services, finance and information-intensive industries are the core of the tertiary industries, and demands on natural resources and environment is essentially lower than in the two former sectors.

Along the path of development, at least in theory (Clark 1940; Fourastié 1949; Drucker 1959), the technologies and knowledge from the advanced phases of development spread to the less advanced sectors. For instance automation, information technology, advanced process technologies, etc. help in pollution control and efficiency development of primary and secondary activities.

Despite the long existence of economic theory on economic transition, the water sector organisations and scholars pay surprisingly little attention to it. For instance, China is now very actively promoting technological reforms in order to combat pollution and move up in the value chains. This means reducing the importance (and at the same time improving technologies) of the secondary, industrial sector, and investing massively in knowledge-intensive tertiary and even quaternary industries. There is already evidence on the rapid sinking of the importance of primary and secondary industries in China, and rapid improvement of water intensity in the water-thirsty primary sector, and even faster improvement of energy efficiency in the energy-thirsty secondary sector (Cai et al. 2016).

At the same time, international agencies keep using and promoting concepts such as 'an industrialised country'. With no link to realities and activities on the ground, such as the Chinese example provided above, this rather creates confusion than understanding.

3.8 Concluding Remarks

As demographics lay the foundation for most of the other megatrends of the planet, and are often part of those megatrends, it is important to know and be realistic with the most significant outlines of demographic development in scrutinising the world's megatrends. This chapter has elaborated some of the key features of global population projections with a specific focus on the time window from 2030 to 2050. The analysis was done in the form of questioning or rather bustering a series of common conceptions or 'myths'.

My thesis is that much of the common debate and even policy development that occurs today around water and other sectors related to the globe's future development and goal setting would benefit for more careful study of demographic facts and future projections. The terminology and many basic concepts would need far more elaboration than what is common today.

The following two recommendations can be made to buster myths of the type that were shown in this chapter:

- Avoid using imprecise and often even misleading jargon terms such as global south, industrialised country and so forth, if there is no real reference to cardinal directions, economic structure, etc. If we talk about countries with low GDP or income level, we should maintain talking about low-income countries. Yet, keep in mind that income level is only one facet of development. Or if the interest is, for instance, in education level, human development or something else, it would be fair and clear to mention it unambiguously. Or if we want to talk about recipient and donor countries of official development assistance, we should simply talk about recipient and donor countries, and not mess around with cardinal directions south and north.
- World demographics is an extremely dynamic process. Even in the time frame of a decade or two, there are vast changes in basic demographic parameters. This was illustrated in, for instance, the case of the PSR. If development scenarios and global megatrend analyses do not pay proper attention on the dynamics of demography and developments in future population prospects, the outcomes are prone to be misleading.

What comes to the demographic features that deserve special attention here, starting from Africa seems obvious and well justified. Africa's future will be a topic of particular concern and interest in the coming decades. Its demographics are quite different from demographics of any other region. Africa is still less crowded than many other regions such as much of Asia and Europe, but its population grows and urbanises very fast. Africa lacks today many prerequisites for conventional economic, political and social development, and hence may be at high risk of massive social and environmental challenges. Nevertheless, here again, extrapolating Africa's recent development may turn out to be quite wrong. Anyway, Africa will be quite different in terms of population in the year 2050 from what it is now.

Urbanisation of Africa and Asia will continue to soar. By the year 2050, Africa's urban population is expected to grow threefold, and Asia's twofold. But Asia's working-age population is not expected to continue to grow very much by that year, whereas Africa's will grow 2.5 times from the present level. Capital formation and industrial development are booming in parts of Asia, particularly in Eastern Asia, but remain remarkably low in Africa. The same tendency applies for formation of human capital. The Chinese and gradually other developing Asian populations will face a dramatic ageing problem very soon, and by 2050 the age profile looks quite challenging in this regard. Africa's population will remain essentially younger by that time.

Europe's, North America's and East Asia's major demographic challenge is ageing, and in these regions, the capacity to face water-related challenges is relatively high. Latin America and the Caribbean, Southeast Asia and Oceania rank close to the global average in all respects considered in this analysis, and the population challenge is more many-sided than in the high-income regions referred to above.

In China and South Asia, urbanisation dominates the demography, whereas in the MENA Region and Sub-Saharan Africa, population growth remains far above the world average. Africa will be a different story than what other regions will have, and most probably, than what can be anticipated after all.

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Chapter 4
Harvesting Experience for Sustainable Urban Water Management

Janet G. Hering and Kalanithy Vairavamoorthy

> *The highest research priority is harvesting experience, in the form of comprehensive and detailed case studies, from many more successful communities. We have paid too much attention to barriers—to research problems that have yet to be solved. It's time to pay attention to these success stories. They can inform and inspire action and start new communities down their own unique roads to successful climate adaptation. For these communities, the highest practical priority is to build on what has already worked, not reinvent it.*
>
> Prof. Emer. Ron Brunner (Univ. of Colorado)

Abstract The urban population exceeded the rural population for the first time in 2007. This megatrend has put increasing stress on urban water supplies and urban water management (UWM). In response to challenges posed by shifting demographics and ageing infrastructure in industrialised countries and severe infrastructure deficits in rapidly-growing cities in low- and middle-income countries, sustainable UWM (SUWM) is being developed and implemented. SUWM encompasses a portfolio of approaches that includes: recovery of water, energy and nutrients from wastewater; expansion of potential sources (e.g. stormwater) for water supply; matching water quality (and hence treatment) to intended use, partial system decentralisation; and using both 'grey' (i.e. fully engineered) and 'green' partially engineered infrastructure. To benefit from the expanding experience with SUWM, effective channels are needed for information exchange, which could serve to promote the uptake of practices with demonstrated success. Knowledge platforms should take advantage of recent advances in information technology to

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combine increased access, reliability and ease of use with responsible curation to ensure the quality of information and avoid conflicts of interest.

Keywords Urban water management · Sustainability · Green infrastructure Knowledge platforms · Polycentricity

4.1 Introduction

Although the remarks by Ron Brunner (Rasmussen 2014) in the epigraph to this chapter were made in the context of climate adaptation, they apply equally to issues of sustainable urban water management (SUWM). Despite the crisis mentality that pervades much of the discussion of water resources and water supply, important steps have been taken to identify and implement sustainable solutions. Cities and communities, with their historic responsibilities for water management (Sedlak 2014; Gardner 2016), are already serving as agents of change in conceptualising, planning and managing the urban water cycle in innovative and more sustainable ways (Suzuki et al. 2010; Howe et al. 2012; OECD 2015). Harvesting experience (i.e. systematically and rigorously validating and documenting examples of success in SUWM) is needed to build a robust evidence base for the implementation of 'what has already worked' in new locations so that resources can be directed toward appropriate adaptation to local contexts rather than wholesale reinvention.

The urbanisation megatrend is a central driver for improving the sustainability of urban water management (UWM). By building on successful experiences and using existing tools, methods and concepts, urban water managers can capitalise on past investments to address their current and anticipated needs. Local contexts will be decisive in setting priorities and selecting among alternative approaches. In this chapter, we discuss urbanisation and its implications for UWM as the background for examining the opportunities to use knowledge platforms more effectively to provide access to the experience, concepts, methods and tools needed to support SUWM.

4.2 The Urbanisation Megatrend

The trend toward increasing urbanisation in both more and less developed regions is not a new phenomenon. The rates of urban population growth from 1950 to 1970 were 2% in more developed regions and 4% in less developed regions, decreasing to 0.9 and 3% in more and less developed regions from 1970 to 2011 (UN 2015). The world urban population exceeded the rural population in 2007; the urbanisation trend is expected to continue with most urban growth occurring in low- and middle-income countries, LMICs (Birkmann et al. 2016; Forman and Wu 2016). Most of the world's urban population today reside in urban areas with populations under 300,000 but this fraction is anticipated to decrease. The next most important size class (in terms of the fraction of the world urban population) is medium-sized cities with populations of 1–5 million. Megacities (i.e. populations above 10 million) accounted for 14% of the world urban population in 2014. Most of the growth in urban population through 2050 is expected to occur in relatively few countries, most notably China, India and Nigeria.

Reflecting the increasing importance of cities, the Sustainable Development Goals (SDGs) include making cities 'inclusive, safe resilient and sustainable' as Goal 11 (http://www.un.org/sustainabledevelopment/cities/). Water is included in Goal 11 explicitly in the target to reduce the impact of water-related disasters and implicitly in the target to reduce the adverse per capita impacts of cities. This latter target is explicitly addressed in Goal 6 'Ensure access to water and sanitation for all' (http://www.un.org/sustainabledevelopment/water-and-sanitation/) in the target to 'improve water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally'.

Throughout history, water management has been a core civic responsibility (Sedlak 2014; Gardner 2016). Given the current and anticipated trends toward increasing urbanisation and the vulnerability of freshwater supply (especially in urban areas) (McDonald et al. 2014; Padowski and Gorelick 2014; Padowski et al. 2015), the issues of UWM are becoming increasing prominent and the need to develop sustainable practices for UWM more obvious. Progress in improving water supply and sanitation in cities in LMICs has not been able to keep pace with urbanisation; it is recognised that 'improved water sources' per se do not guarantee that water is free from pathogens and lack of trust in the safety of municipal supplies has led to increasing reliance on bottled water as a main drinking water source in some urban areas (WWDP 2015). The need to understand cities as 'social-ecological-infrastructural' systems incorporating diverse actors, priorities and alternatives for action is as relevant for the water sector as for other sectors such as transportation, energy supply, building stock and green spaces (Ramaswami et al. 2016).

4.3 Urban Water Management

Given the long history of UWM and its implementation under widely varying local contexts (Sedlak 2014), it is unsurprising that UWM incorporates many forms and approaches. In modern times, however, conventional UWM is dominated by practices developed in Western Europe and North America, which necessarily reflect those climates and the preponderance of urban settlements on major rivers or coasts. This has led to a conventional paradigm in which water is used for waste conveyance and the rapid conveyance of stormwater away from urban areas to prevent flooding is prioritised. Conventional practice has been strongly oriented toward system centralisation and has emphasised the strict separation of drinking water and wastewater to protect human health.

The climates in the countries where the most urban growth is anticipated (i.e. China, India and Nigeria) differ dramatically from those where the conventional UWM paradigms were developed. Water storage in monsoon climates is particularly challenging. Even in Western Europe and North America, the combinations of changing demographics and ageing infrastructure pose challenges to conventional UWM practices (OECD 2015). This creates opportunities to consider alternatives to conventional practices both in the end-of-life replacement of infrastructure and in new or expanding urban areas (Farrelly and Brown 2011; Larsen et al. 2016). Shifting from conventional to sustainable UWM opens new avenues for addressing the vulnerabilities to freshwater supply that cities face (Howe et al. 2012; McDonald et al. 2014; Padowski et al. 2015). The development and implementation of SUWM is a response to the urbanisation megatrend and the recognised limitations of conventional UWM.

4.3.1 Key Aspects of SUWM

In keeping with the meta-principle for sustainable cities that 'recognise[s] diverse strategies for resource efficiency in different city types' (Ramaswami et al. 2016), SUWM encompasses a portfolio of approaches with a focus on the 'circular economy' in which the recovery of water, energy and nutrients allows 'wastewater' to serve as a resource (Grant et al. 2012; Hering et al. 2013; Larsen et al. 2016). In addition, SUWM aims to match the quantity and quality of water to its intended use, avoiding the need for the highest level of treatment for all waters. This exposes alternative sources of water (e.g. stormwater) that can be safely used for different purposes, reducing gross water abstraction and water treatment costs. SUWM also breaks away from the paradigm of favouring fully centralised systems to incorporate a continuum of (de)centralisation; operation at multiple scales can be addressed through the concept of polycentricity (van Kerkhoff and Szlezak 2016). Decentralisation has the benefit of co-locating treatment and reuse so that (energy) costs associated with pumping can be minimised. SUWM relies not only on fully engineered systems (i.e. 'grey' infrastructure) but also incorporates partially engineered systems in which engineering objectives are achieved through natural processes (i.e. 'green' infrastructure) (Shuster and Garmestani 2015). Examples include the Green Stormwater Infrastructure (GSI) implemented in the City of Philadelphia, which uses installations including tree trenches, permeable pavement and green roofs to increase stormwater percolation into the soil (National Academies 2016), and the Sponge City programme in China (Li et al. 2016).

Implementation of (partially) decentralised systems has several potential benefits. The expensive construction and/or renewal of sewers can be minimised and the demand for water for waste conveyance can be reduced. By avoiding the dilution of waste, the need to treat large volumes of wastewater is also avoided and resource recovery processes can be optimised for high(er) strength ‘waste’. An additional advantage of decentralised systems is their adaptive capacity—the ability to develop in stages and grow incrementally over time, enabling them to better respond to the inherent uncertainties associated with global change pressures (Eckart et al. 2010). Their distributed nature also makes them more resilient to the impact and propagation of shocks. It is, however, more difficult to monitor and control performance in (partially) decentralised systems. New technologies (i.e., sensors and control systems) as well as changes in system management and governance are needed to ensure that water quality standards are met (Hering et al. 2013).

Engagement of stakeholders in planning, decision-making and implementation processes is considered to be an important factor in the success of SUWM. Stakeholder engagement has the potential to break down barriers to information sharing and learning and speed up the identification, development, and uptake of solutions related to urban water management (Butterworth et al. 2009; Howe et al. 2012). Cities in the USA have made major efforts to include stakeholders in planning of sustainable water infrastructure and management, for example in Pittsburgh (National Academies 2016). Stakeholder engagement imposes undeniable transaction costs; strategies to engage stakeholders must address their motivations and efforts are required to bring stakeholders together (Butterworth et al. 2011). Studies in low-income countries indicate that earlier and more intensive participation in Household-centred Environmental Sanitation planning processes conducted in urban areas in Nepal and Lao People’s Democratic Republic were associated with greater satisfaction regarding the outcome and implementation as well as higher willingness to pay and to participate in future participatory processes (Luethi and Kraemer 2012). A study of handpump sustainability conducted in rural Ghana underscores the importance of the depth (i.e. intensity) of stakeholder engagement (Marks et al. 2014).

4.4 SUWM in a Development Context

Although urbanisation in LMICs poses many challenges, the absence of ‘lock-in’ associated with mature infrastructure, governance structures and urban planning also offers opportunities to implement new paradigms for UWM (Brown et al. 2009; Vairavamoorthy et al. 2015). To meet the needs of developing countries, a tailored integrated framework must consider their characteristic water and sanitation practices. The framework must capture the consumption patterns from taps, private wells, water kiosks and private water vendors and account for intermittent supply, high leakage and low-pressure conditions in water distribution systems (where they exist). Even where adequate water treatment is provided at the treatment plant, intermittent supply and low water pressure allow seepage of chemical and microbial contaminants into the distribution system resulting in the deterioration of water quality. The variety of different on-site and off-site sanitation options such as pit latrines and septic tanks must also be included as well as the pollution of potential water sources resulting from poor sanitation and the (common) absence of wastewater treatment. An additional consideration is the use of wastewater for irrigation of urban agriculture, which has the advantage that the scarce water resources are used multiple times but increases public health risks by spreading the pathogens along the food chain (Qadir et al. 2010; Liebe and Ardakanian 2013). Nonetheless, market-driven crop production on urban open spaces can be both highly productive and profitable (Drechsel and Dongus 2010). Possible constraints on SUWM practices resulting from other urban development (e.g. reduced opportunities for stormwater infiltration associated an increase in impermeable surfaces) must also be considered.

4.4.1 SUWM Concepts, Networks and Tools

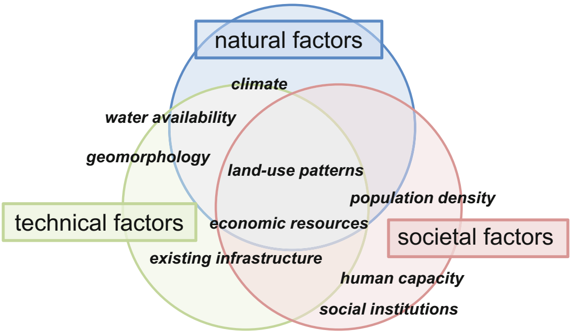
Urban sustainability, including SUWM, is an increasing focus of attention in cities worldwide (National Academies 2016). Information on the concepts, networks and tools that have been developed and are being implemented as well as the experience gained through the implementation of SUWM practices needs to be made accessible and usable to support expanded uptake of SUWM.

4.4.1.1 Concepts

Like all efforts to improve sustainability, SUWM recognises that measures to improve human welfare will ultimately be self-defeating if they result in the impairment of critical ecosystem functions. By dealing with cities as 'social-ecological-infrastructural' systems (Ramaswami et al. 2016), SUWM can account for the combination of natural, technical and societal factors that contribute both to pressures on the water environment and the capacity for SUWM (Fig. 4.1). In this framework, it is clear that deficits in one type of factor, such as limited natural water availability, could be offset by demand management and/or infrastructure for water storage or aggravated by inadequate human capacity and economic resources. Similarly, demand, endowment, infrastructure and governance 'characteristics' were identified in an analysis of freshwater vulnerability (Padowski et al. 2015). It must also be recognised that the water footprint of cities extends well beyond the urban boundary due to both water conveyance and the transport of virtual water in agricultural products (Hoff et al. 2014; McDonald et al. 2014; OECD 2015; Paterson et al. 2015).

SUWM shares some of its theoretical underpinnings with integrated UWM (IUWM) (Bahr 2012), in particular, the 'one water' practice of managing all of the elements of water supply, stormwater, and wastewater as an integrated, (ideally) closed loop. The main difference is that, in SUWM, integration is considered as a *means* to the end goal of sustainability, rather than as an end in itself. Integration

Fig. 4.1 Overlapping contributions of natural, societal and technical factors to the capacity for sustainable water management



can bring substantial benefits but also carries transaction costs and may be infeasible when boundaries of formal authority are not compatible with integration (Hering et al. 2012; Hering and Ingold 2012). Nonetheless, the principles that inform IUWM and, more generally, integrated water resources management (IWRM) are also broadly applicable to SUWM. A variety of case studies have also been conducted (see also the sub-section *Tools* below), but the generalisations that would link the overarching principles with specific applications are often lacking. This is illustrated schematically in Fig. 4.2, in which specific measures (level 'WHAT') developed on an ad hoc basis in a local context would ideally be linked to the overarching goals and principles (level 'WHY') through general and generalisable concepts (level 'HOW').

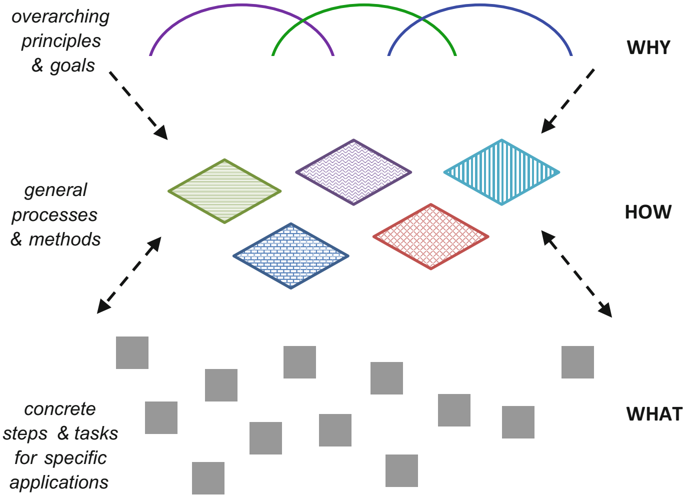


Fig. 4.2 Schematic illustration of levels of conceptual organisation from the overarching ('WHY') to the concrete ('WHAT'). The intermediate level that links these ('HOW') is often neglected

4.4.1.2 Networks

Cities have already established networks related to resource management and environmental issues, particularly climate change adaptation. Two well-established examples are the International Council for Local Environmental Initiatives (http://www.iclei.org/), which was founded in 1990 by 200 local governments from 43 countries, and the broader United Cities and Local Governments (http://www.uclg.org/) founded in 2004. About 10 years ago, the organisation C40 Cities (http://www.c40.org/) was established to bring the largest cities (especially the megacities) together to focus on climate change adaptation. This group now includes over 80 of the largest cities worldwide. In 2013, the organisation 100 Resilient Cities (http://www.100resilientcities.org/#/-_/) initiated activities with a first cohort of 32 cities to develop roadmaps for resilience. Although water management, per se, is not a major focus for any of these organisations, C40 Cities recently partnered with the Nature Conservancy and the International Water Association (IWA) to develop an Urban Water Blueprint (McDonald and Shemie 2014). A specialised network of water operators (http://gwopa.org/en/) has been established to share information and good practices in water supply. Consensus documents related to urban water management have been signed at the World Water Forum (WWF 2009). Conferences serve as an important venue for information exchange and support of mutual interests. Conferences focusing on urban issues include: the International Making Cities Livable Conference (http://www.livablecities.org/), the Mistra Urban Futures Conference (http://www.mistraurbanfutures.org/en), the Urbanisation and Global Environmental Change Conference (http://www.ugec2014.org/), and the World Urban Forum (http://unhabitat.org/wuf/).

4.4.1.3 Tools

A variety of tools relevant to SUWM have been developed. Some of these address more general issues of urban resilience, often focusing on identifying indicators for sustainability and/or resilience (Suzuki et al. 2010; Science for Environment Policy 2015; National Academies 2016). Specifically for the water sector, Organisation for Economic Co-operation and Development (OECD) reports provide an overview of issues related to financing, diffusion of innovations and urban-rural co-operation (OECD 2015) as well as a list of links related to water governance (OECD 2014). Water footprint analysis and related methods (e.g. lifecycle assessment) have been applied to assess water sustainability of urban regions, particularly related to consumption; this highlights the urban impact on remote regions through the import of virtual water (Hoff et al. 2014; Paterson et al. 2015). City water maps have been used to characterise the dependence and stress on urban water supplies, highlighting the physical conveyance of water from (sometimes remote) watersheds (McDonald et al. 2014). Models developed for IUWM, which include all urban water flows (blue, white, grey and black water) as well as their integration through recycling schemes (Bach et al. 2014), are also applicable for SUWM. These models are generally water-balancing models that provide a structured approach to identify a portfolio of water sources, prioritise their selection, and assess water flows and contaminant fluxes within an IUWM strategy and can be used to investigate alternative water management strategies. The City Blueprint Index was developed to characterise performance of cities using a variety of indicators directly and indirectly related to water management (Koop and van Leeuwen 2015a, b; Van Leeuwen et al. 2016). The Urban Water Blueprint provides information on measures that have been or could be used to improve the sustainability of UWM (McDonald and Shemie 2014). Measures to decouple the degradation of water resources (including water pollution) from economic growth are described in a recent United Nations Environment Programme (UNEP) report (UNEP 2015). For the challenging issue of sanitation management in LMICs, SFDs (Shit Flow Diagrams) provide a visualisation of safely and unsafely managed excreta (http://sfd.susana.org/). The elaboration of indicators for SDG targets also provides definitions and tools for water and sanitation under Goal 6 (https://www.wssinfo.org/sdg-baselines/). Examples of resource toolboxes are listed in Table 4.1.

Table 4.1 Examples of resource toolboxes relevant to SUWM

Name	Organisation(s)	Comments	URL
100 RC platform	100 Resilient Cities	Curated suite of resilience-building tools and services, provided by partners from the private, public, academic, and non-profit sectors	http://www.100resilientcities.org/partners#/-_/
Effective utility management resource toolbox	American Public Works Association, American Water Works Association, Association of Metropolitan Water Agencies, National Association of Clean Water Agencies, National Association of Water Companies, Water Environment Federation, US Environmental Protection Agency (EPA)	Intended to support effective utility management collectively and individually throughout the water sector and to develop a joint strategy to identify, encourage, and recognise excellence in water and wastewater utility management	http://www.watereum.org/resources/resource-toolbox/
IWRM toolbox	Global Water Partnership	A free and open database with a library of background papers, policy briefs, technical briefs and perspective papers as well as huge sections of case studies and references in each tool	http://www.gwp.org/en/ToolBox/

(continued)

Table 4.1 (continued)

Name	Organisation(s)	Comments	URL
Leaders innovation forum for technology	Water Environment Research Foundation; Water Environment Federation	Intended to help bring new water technology to the field quickly and efficiently	http://www.werf.org/lift
Sustainable sanitation and water management toolbox	seecon gmbh	The Toolbox contains: background on environmental, economic and socio-cultural issues; factsheets and presentations of tools for Planning and Processing and for Implementation, 'mini-toolboxes' on specific topics, training material, library and glossary	http://www.sswm.info/
Toolbox	UN Water	Gathers existing practical guidance which could be useful for the implementation of the different targets proposed for the water related SDGs	http://watersdgtoolbox.org/
Watershare®	Membership organisation led by KWR Watercycle Research Institute	Selected partner knowledge institutes from all over the world share in the use of expert water-related tools	https://www.watershare.eu/

4.5 Knowledge Platforms to Support SUWM

Many of the resources and networks discussed above are web-based, offering potential access to a wide range of options for SUWM. Some of the existing platforms (e.g. the 100RC Platform and Watershare$^{®}$) are intended to facilitate exchange among partners and/or members. It would be difficult to claim, however, that the existing platforms are optimally structured to promote uptake of practices with demonstrated effectiveness. In addition, the sheer number of platforms is daunting and exacerbated by the lack of effective cross-referencing among them.

Ideally, knowledge platforms would be structured to guide prospective users intuitively through the available information with an interface that supports interactive queries. In the specialised area of sanitation systems and technologies, an example of this approach is the eCompendium (http://ecompendium.sswm.info/). In this interactive tool, users can design sanitation systems using templates with reference to standardised technology information sheets.

Similarly, a web resource provides support for water treatment plant design; detailed plans for the design of coagulation/flocculation plants can be modified for

Fig. 4.3 Home page for the IUWM tool kit developed by the Global Water Partnership (GWP), the University of South Florida, the International Water Management Institute (IWMI) and the water partnership programme of the World Bank (PCGS et al. 2015). Release is anticipated in 2017

implementation (https://confluence.cornell.edu/display/AGUACLARA/Home). This is supported by online access to (near) real-time information on the performance of constructed treatment facilities (http://monitor.wash4all.org/).

A new resource now being finalised is the IUWM Tool Kit (Fig. 4.3). The Diagnostic Tool, in particular, provides a standardised process for analysing UWM sub-systems and bench-marking performance metrics. This could also serve as the basis for harvesting experience on specific SUWM applications.

With the megatrend of rapid advances in information technology, knowledge platforms should offer increasing access, reliability and ease of use; responsible curation is needed to ensure the quality of information and to avoid conflicts of interest. As new platforms emerge, for example the ‘mobilise’ platform being developed by the Sustainable Development Solutions Network (http://unsdsn.org/), the ‘open network’ being developed by Future Earth (http://www.futureearth.org/) and the online platform being developed by the United Nations (UN) Technology Facilitation Mechanism (https://sustainabledevelopment.un.org/TFM), it will be important that some leveraging of efforts (at the very least, cross-referencing) is incorporated. A federated approach could help to create shared ownership (and credit), mitigating the effects of the ‘not-invented-here syndrome’. Web resources should be designed to allow expansion for data sharing and reuse across application, enterprise and community boundaries (i.e. the semantic web) as illustrated by the Global Water Platform (http://www.globalwaterplatform.org/). This is needed to support data-mining and machine-learning. It will also be necessary to support co-production of knowledge, which bridges the gap between experience-based and research-based knowledge (Cash et al. 2006; Pohl 2008; Pahl-Wostl et al. 2013) to allow the integration of 'high- and vernacular technologies' (Ramaswami et al. 2016). Lastly, knowledge must be redefined as a global public good rather than a private asset (van Kerkhoff 2013).

4.6 Outlook and Recommendations

There is a strong momentum for the transition from conventional to sustainable UWM. Opportunities are created in industrialised countries by the need to accommodate changing demographics and replace ageing infrastructure and, in LMICs, by the urbanisation megatrend and the need to provide services for new and expanding urban areas. Researchers have developed concepts and tools to support the transition to sustainability, some of which, like the SWITCH Transition Manual (Jefferies and Duffy 2011), are the products of joint projects with cities, their water managers and stakeholders. Cities have also taken the lead in incorporating SUWM into their planning, implementing (more) sustainable practices and creating and participating in networks intended to promote the sharing of experience-based knowledge (National Academies 2016). They are supported in this endeavour by boundary organisations (like 100 Resilient Cities) that can link research- and evidence-based knowledge, increasing the salience, credibility and legitimacy of co-produced knowledge (Cash et al. 2003). This is particularly important to offset the tendency of 'lessons being lost', which reflects the fact that often neither program managers or funding agencies have a primary interest in capturing lessons from experience and/or codifying them in best-practice repositories (van Kerkhoff and Szlezak 2016). Academic researchers could play an important role in supporting these efforts and also in merging SUWM content knowledge with forefront information technology. This is urgently needed to help build the next generation of knowledge platforms to support SUWM and achieve the goal of moving 'from data to information to knowledge and, ultimately, to action for urban sustainability and human well-being' (Ramaswami et al. 2016).

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Chapter 5
Future of Water Resource Recovery

James W. Hotchkies

Abstract Throughout history, wastewater has been viewed as an inconvenient problem and, most significantly over the past century, an agent of serious environmental impact. While we have, for the most part, developed solutions that mitigate health risks in most industrialised countries, we have fallen short on managing sanitary wastewater in less-developed regions and on increasingly complex industrial wastewater. Over the past few decades, a series of changes and influences—regulatory, societal, environmental and technological—have created an increased awareness of the issues and opportunities around wastewater. Concurrently, major advances in technology have created the potential not only to mitigate the negative impacts of wastewater but to redefine it as a resource to be mined. As we move forward, our ability to recover valuable resources from wastewater, to harness the energy potential in the spent organics in the stream and to recover almost 100% of the water for myriad reuse applications, will return us to a more natural environmental model where waste is simply fuel for the next process in our ecosystem.

Keywords Urban development · Water resource recovery · Wastewater
Regulations · Contaminants

5.1 Introduction

For most of our history, wastewater has been considered a problem and a nuisance to be managed. We consume significant quantities of clean, potable water—in some areas more than 200 L per capita per day—to flush toilets, rinse manufactured items, wash floors and other essential demands of today's society. Most of the water we take from our aquifers, rivers and lakes is used once, in a single-pass operation, and then 'treated' at a centralised municipal plant or a decentralised facility prior to

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discharge back to the environment. Finally, while effective in improving human health immensely, many of these traditional treatment plants continue to be designed around a technology that has basically not changed over the past 100 years.

In a world that is experiencing massive population growth, demographic shifts to significantly higher per capita water consumption and urbanisation in water-scarce regions, we can no longer ‘waste’ this necessary and precious resource as we have in the past.

Fortunately, while the demands for even greater amounts of water by our communities, industries and agriculture continue to grow, our ability to develop and leverage a suite of new, effective and affordable technologies is encouraging. Whether adapting solutions to extract energy and nutrients from wastewater or recycling almost 100% of wastewater to safe, potable reuse quality, we have the means to address the demands of tomorrow’s world at hand or under development.

The challenge is to shift our mindset from viewing wastewater as a problem to seeing it as a source of resources to be harvested.

5.2 The Traditional View of Wastewater

For most of our history, our communities and industries have used water extensively to function and develop. Almost without exception, water has been used in single-pass processes, whether to process food products, quench coke in steel mills, wash the floors of industry or flush toilets. At the end of this once-through use, the used water—typically described as wastewater—is discharged back to the environment. In its use, the water used in these myriad processes may capture or absorb a wide range of contaminants.

In most advanced, industrialised countries, wastewater from both municipal sewers and from commercial and industrial processes is treated to reduce the overall impact on the environment, by either decentralised or centralised treatment facilities. Unfortunately, in many developing economies and most undeveloped regions, wastewater is often returned to the environment with only very basic primary screening for gross solids removal or without any treatment whatsoever. In the slums surrounding many of our most populous cities, completely untreated sanitary sewage runs freely in open ditches. Highly corrosive or toxic wastewater from mining operations, chemical processing facilities and oilfields continue to degrade our environment in many locations around the world. Even in our most developed economies, a host of newly developed micropollutants, which may not be effectively treated with current technologies, create unique hazards and continue to stress the environment.

Where we do have effective and enforced regulations, and where the dominant contaminants are organic, the treatment process adopted is typically a variation of the activated sludge process, basically unchanged for over 100 years, as illustrated in Fig. 5.1.

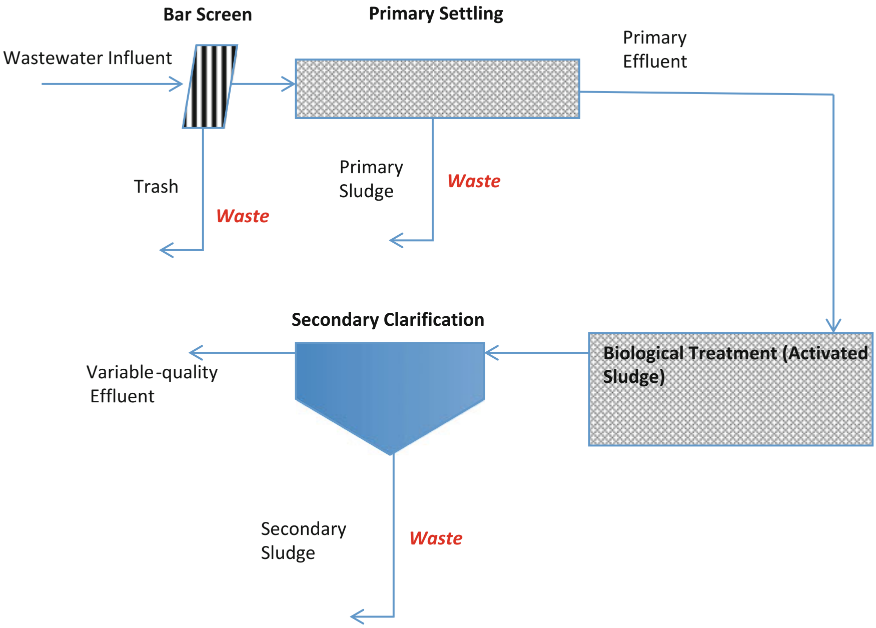

Fig. 5.1 Today's typical municipal wastewater treatment plant

This process has been an extremely successful approach to managing wastewater, reducing the potentially detrimental effect such contaminated waters could have on our environment and effectively minimising the spread of extremely dangerous pathogens back into our communities. However, as illustrated in Fig. 5.1, the process generates significant quantities of waste at each step of the operation. In many operations, these wastes are accumulated and transported for disposal at a secure landfill as a waste sludge. In the truest sense of the word, this is a waste. Buried for decades in these landfills, or similar disposal locations, any potential beneficial value that could exist in these sludges is effectively gone forever.

Also, as qualified above, the positive impact such wastewater management operations has on human health and environmental preservation depends on not only having strong regulations in place but, as importantly, on ensuring the enforcement of them. Too often, we have seen the negative consequences of enacting good, potentially effective standards and regulations, to significant fanfare, without the concurrent implementation of any serious enforcement.

With wastewater containing primarily inorganic contaminants, such as from a mining or metals processing operation, traditional treatment operations focused on either sequestering the contaminated wastewater in a storage pond or removing the contaminants as a precipitated solid or as a concentrated brine. In many cases, these solids and brines were again converted into sludges for disposal at a landfill. Again, any potential value from the metals or salts that were present in the sludge was lost forever.

Furthermore, in many of our less-developed or minimally regulated regions, highly toxic and hazardous industrial effluent discharges from poorly managed tailings ponds, unlined landfills and over-fertilised farm land has killed rivers and lakes, and rendered large amounts of agricultural land barren.

5.3 An Awakening

Over the past couple of decades, however, there has been a growing recognition that our society had abused our precious water resource to an extreme level and that our management of wastewater, even in our industrialised economies, was completely unsustainable. We have also seen that, in locations from Miami to Montreal and Mumbai, man-made spills and natural disasters frequently result in major, unplanned releases of untreated wastewater to the environment.

Concurrently, technology has advanced over the same period to the point that many contaminants seemingly locked in the wastewater and not technically or economically recoverable, now start to become a potential resource.

From sanitary effluent streams, we can now start to convert the organic waste fraction into a biofuel or even a biopolymer. In Denmark, at the Marselisborg Wastewater Treatment Plant, we have succeeded in changing a municipal wastewater treatment plant from a large energy consumer into an energy producer, covering not only all its internal requirements but as much as 130% more.

We can harvest phosphorus, a globally limited resource that is essential for food crop production, to be recovered and processed into a high-value fertiliser. From Portland, Oregon, to Berlin, London and Chicago, dozens of facilities are either under construction or already in operation, using a variety of technologies and processes, to extract this essential resource and to convert it into a useful, revenue-generating resource.

In addition, we can recover almost 100% of 'used' water and treat it to safe, potable reuse quality, if required. From centralised municipal plants in Singapore to decentralised condominiums in New York City and hotels in Barbados, very robust and cost-effective technologies are treating sanitary effluent to a range of fit-for-purpose qualities, suitable for safe landscape irrigation to even bottled water purity.

From the tailings ponds at mines, we can now employ advanced technologies to economically recover extremely valuable trace metals and the acids typically used in the extraction and processing operations.

At food and beverage processing facilities, from boutique wineries in Ontario to breweries in Australia or dairy processors in the Netherlands, we have compact, affordable, low-energy technologies that can reduce high-strength discharge loads by 90%, capture and recover fats, oil and grease (FOG) for use as a fuel supplement and recycle almost 100% of the streams used to clean the processing equipment.

If we look at the influent to a typical municipal wastewater treatment or pollution control plant, the stream is, in reality, mostly water with a mixture of dissolved and suspended solids: organics, inorganics and nutrients along with varying quantities of inert trash.

Around 70% of the organic materials, typically measured as BOD_5, are suspended solids, or non-soluble organics, while the balance is dissolved solids or may be referred to as soluble BOD. With an Enhanced Primary Interceptor, up to 90% of this non-soluble organic material flowing into the plant as raw sewage could be captured as ‘primary sludge’ and transferred to an on-site anaerobic digester for conversion into biogas.

Then, this reduced-solids stream, termed Primary Effluent, would flow to the Secondary Treatment Module where the remaining organic material would be biologically digested by beneficial bacteria and converted into carbon dioxide, oxygen, nitrogen and dead cell matter.

Increasingly, advanced processes, such as the Membrane Bioreactor or similar high-efficiency technologies are being employed to reduce the physical footprint of the operation and to enable the production of reliable, reuse-quality treated water. In these processes, beneficial bacteria are used to biodegrade the organic material. A steady feed of air is provided to satisfy the oxygen demand of the microorganisms.

In a typical sanitary wastewater stream, removing 90% of the non-soluble organic material results in an overall reduction in the total organic load of up to 66% and this, in turn, reduces the amount of air required by the bacteria by a similar amount. This also reduces the energy required by the Secondary Treatment Module by a similar ratio.

The fully treated stream, termed Secondary Effluent, might then flow to a high-efficiency disinfection process, such as ultraviolet, prior to being discharged as reuse quality water, suitable for any non-potable application.

The solids, which are mostly dead cell matter, are removed from the Secondary Treatment Module. Described as Secondary Sludge, these waste solids could then be blended with the Primary Sludge in the Anaerobic Digester. An additional benefit of the Enhanced Primary Treatment is that the Primary Sludge has a significantly higher fuel potential than Secondary Sludge, and the energy production of the Anaerobic Digester may exhibit an increase of 400% or more.

Finally, the phosphorus-rich waste from several stages in the new facility may be treated in one of several recovery systems to produce a high-value Magnesium-Ammonium-Phosphate (MAP) fertiliser.

The end result, even today, is the conversion of a Wastewater Treatment Plant (WWTP) into a Water Reclamation and Resource Recovery facility (see Fig. 5.2). Under the right conditions, such a facility can now be energy neutral or even energy positive. This is a significant advance on the majority of today’s plants where extremely large amounts of energy are consumed of the process of ‘wasting’ precious and valuable resources.

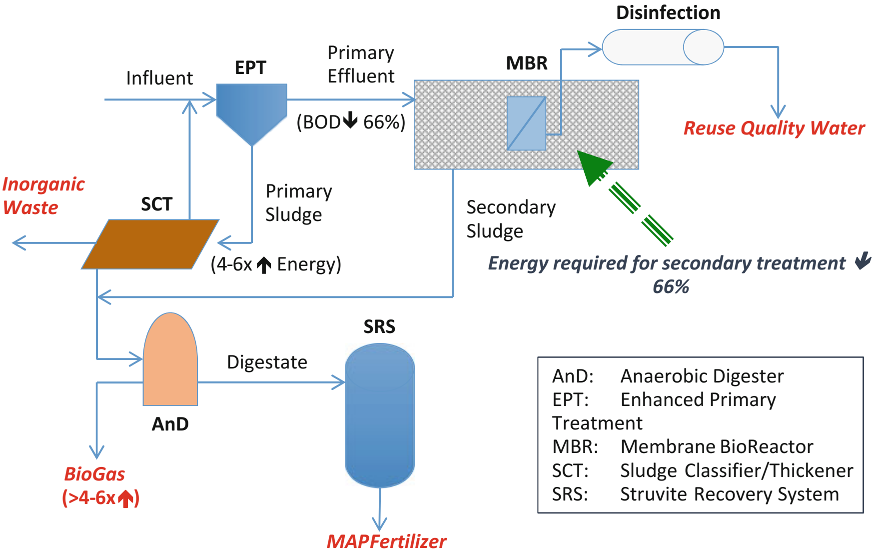

Fig. 5.2 Tomorrow's typical municipal WWTP

5.4 A Convergence Megatrend

The above-noted model of a municipal sewage processing facility is just one of many configurations and concepts available today to improve dramatically the management of municipal wastewater. Similar process models are also available for application in breweries and dairies, mines and steel plants, textile manufacturing and pharmaceutical production, and a host of other industries.

This fundamental shift in our thinking, that these are not simply wastes to be treated and disposed but high-value resources to be mined, is a megatrend that has been enabled by the convergence of several drivers and enablers, including regulatory pressure, societal pressure, resource scarcity and technology.

As we have improved our ability to detect and assess the potential impacts from an expanding universe of pollutants, the pressure on municipalities and industries to eliminate them from the environment, or at least mitigate their effect, has increased significantly. For example, the need to eliminate or reduce significantly the discharge of concentrated brine from desalination plants has placed significant barriers to development. The cost of compliance with evolving regulations has risen considerably, particularly in areas such as the discharge of high organic loads to municipal sewers, the discharge of endocrine disruptors or the run-off of fertilisers from agriculture. In many urban areas, there are strict limitations on sludge disposal from wastewater treatment operations and the costs associated with transporting these wastes to areas willing to accept them is extremely high.

In most parts of the world, public attitudes are changing and raising the importance of improvements in quality of life. Communities are demanding access to better sanitation and protection from industrial pollution, enhancing human health and mitigating environmental degradation. Tourism is becoming an increasingly significant generator of revenue in many developing regions and the negative impacts of poor sanitation, whether related to the health and safety of visitors or on the ecosystem such as ocean reefs, has underscored the importance of effective and enforced regulation.

The rapid pace of urbanisation, particularly in water-stressed regions, has highlighted the need for water conservation and water reuse. The ever-increasing demand to improve agricultural yields has, in turn, increased the demand for fertilisers such as phosphorus, a globally limited resource. Our almost insatiable appetite for energy, whether for data centres or megacities, forces us to explore all possible opportunities for alternative energy production.

Advances in detection and analysis now enable us to identify and assess the impact of myriad pollutants and contaminants. Advances in data management and processing now enable us to evaluate how past and current human activity can impact our health, quality of life and even survival.

Advances in engineering, materials and materials processing now enable us to realise unprecedented achievements. We have the ability to reuse almost 100% of the water we consume in our communities and industries. We have demonstrated that the wastewater facility can become energy neutral or even energy positive. In scores of treatment facilities, we are recovering most of the phosphorus in the wastewater stream and converting this into a high-value fertiliser. At mining operations around the world, we have the ability to convert what was once a hazardous waste in the tailings ponds into a source of trace metals and acid. Critically, we now have the ability to achieve these benefits effectively, safely and affordably.

Any survey of the activities underway at universities, environmental centres of excellence, technology providers and the manufacturing sector will illustrate the range of solutions being developed for energy efficiency, resource recovery and system optimisation, and the pace at which these are occurring.

This convergence of key drivers, an evolving understanding of how many disparate elements may interact to affect our world, emerging technologies and an ability to respond, is pivotal to shaping our awareness of what we previously considered a waste is actually an opportunity.

5.5 A Positive Outlook

While our society faces many challenges, from water scarcity to food security and emerging pathogens, our potential for addressing them and developing the necessary solutions is formidable.

In wastewater, the key is to stop thinking of waste and wastewater as problems and to view them as resources we can harvest.

As noted, we now have the ability to build zero-energy or even energy-positive Wastewater Treatment Plants; we have the technologies to recover 100% of 'used' water for any potable or non-potable application; we can recover over 80% of the phosphorus from municipal and industrial wastewater as a high-value, slow-release fertiliser; we can eliminate most of the ammonia from wastewater streams and recover it as a fertiliser feedstock; we can achieve Zero Liquid Discharge (ZLD) on brackish water; we can affordably recover valuable metals, such as gold and molybdenum, and acids from mine tailings ponds.

The list of opportunities for managing what we have traditionally called wastewater and for seeing it as a resource to be mined is large and expanding by the day.

We don't have technology barriers to addressing water scarcity and waste management*, *we just have to overcome inertia and the resistance to change.

While any vision of the future made though today's lens is subject to many potential variables, the water industry tends to be conservative and subject to significant internal inertia. That said, we can identify a number of basic drivers that will shape the industry over the next 10–15 years and a range of technology directions that will continue to develop.

Whether looking at sanitary wastewater or a range of industrial streams from breweries and wineries to mines and chemical plants, key drivers that are identified across all verticals include water and energy footprint reduction and resource recovery.

In the beer industry, an emerging goal is to drive the water consumption from 8–9 L of water for every litre of beer to less than four. In the municipal wastewater sector, we have seen how several European communities have pivoted from energy consuming operations to energy neutral or even energy positive facilities. At potato processors in Belgium and at mining operations in Canada, we now have clear examples of where we can economically recover phosphorus and trace metals.

From these and other complementary drivers, and observing many of the technology development directions underway around the world in industry, at research centres and at universities, significant opportunities exist to drive this trend even more aggressively.

From New Zealand and the USA, developments in ultra-low-energy osmosis will allow us to manage high-strength industrial wastewater and to desalinate water at significantly lower cost. Employing innovations from Australia, Israel and Ireland, we can employ passive aeration or membrane aeration technologies to lower the cost of organic wastewater treatment dramatically.

Next generation polymer and ceramic membrane technologies from Japan, Korea and Israel now allow us to recover metals and acids from mining operations or to purify caustic cleaning solutions in metal-finishing and food-processing operations effectively and economically. Low-temperature anaerobic digestion technologies from Ireland offer attractive new business models for the conversion of organic waste to energy.

Zero or Minimal Liquid Discharge (ZLD or MLD) processes developed in the UK, Canada and the USA, and employing technologies from advanced oxidation to membrane-based brine concentration, will continue to reduce the environmental impact of industrial activities from mining to oil production, or from desalination plants. From many countries around the world, new approaches to the management and mining of waste sludge are improving dramatically our ability to recover nutrients such as phosphorus or to generate energy, and to minimise the cost and impact of disposal.

In nature, there is no such thing as waste, just raw material for another process. With the knowledge, products and processes we already have in our toolbox and those on our doorstep, we have few technology barriers in our path toward a sustainable society, only those we impose on ourselves.

Chapter 6
Smart Water and Water Megatrend Management and Mitigation

David A. Lloyd Owen

Abstract Population growth, urbanisation and climate change are megatrends that are placing unprecedented pressures on renewable water resources and the way they are used. This chapter reviews the potential for smart water approaches to meet these challenges. Smart water covers the use of communications, data processing and data presentation to allow the monitoring and management of water resources in as near real-time as feasible. While smart water is still an emerging suite of technologies and techniques, there is already a substantial body of evidence to show its potential as a disruptive force in modifying consumer behaviour and for the more efficient monitoring and management of water assets.

Keywords Water · Smart water · Megatrends · Demand management
Measuring water consumption

6.1 Introduction

This chapter reviews the potential for 'smart water' approaches to lower water demand along with the costs of developing and operating water and wastewater assets.

Smart water (the use of integrated real-time data collection, transmission, analysis, presentation, and management for water and sewage systems) is an emerging approach with a significant potential to transform the performance of the asset-heavy but funding-light business of water provision and wastewater treatment. Smart water can be applied to water utilities, along with irrigation, industrial, commercial, municipal and residential users. As well as water distribution and usage, wastewater distribution, treatment and recovery, it also covers water flows, quality and saturation in the built and natural environment.

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By providing water managers information in real or near-real time about the state of water both in the ambient environment and water networks, the management of these networks can be optimised with regards to the amount of water needed, the cost of their operations and the most efficient deployment of treatment and distribution assets. For water users, real or near-real-time information enables them to use water in the most efficient manner, lowering the cost of their water use while ensuring they obtain the greatest utility from it.

6.2 Smart Water: The Concept

The Organisation for Economic Co-operation and Development (OECD) (OECD 2012) observed that smart water 'is something of a catch-all expression' and that despite being a part of water management in various forms for the past decade, in practical terms 'its definition and role remains a work in progress' and that it is not intended to replace how services have been operated, rather to improve them and therefore to become 'an enabler of innovation, as much as being an innovation itself'. Four main users of smart water related information have emerged in recent years: (1) utilities seeking to optimise the efficiency of their operations (for example, lower distribution losses, less energy used, improved billing and maximising the operating lives of their assets); (2) domestic customers seeking to manage their water and energy bills; (3) irrigators, seeking to lower the amount of water used and where appropriate, to optimise crop yields; and (4) those involved in monitoring and managing water in the natural environment, such as assessing inland water quality and assessing flood vulnerability.

Smart water is an emerging aspect of water and wastewater management, and, as such, information about its development and deployment is limited. This is reflected in the literature seen with the exceptions of company presentations at conferences and specialist media covering the water and utilities sectors. Most reviews are concerned with developing smart water approaches and examining their potential at various stages of development. Savić et al. (2014), for example, describe developing smart metering frameworks for three domestic meter networks, while Boyle et al. (2013) reviews the how urban smart meters are being deployed. Smart methodologies for optimal network sensor placement (Christodoulou 2015), maximising the operational life of pipe leakage sensors (Sadeghioon et al. 2014) and neural networks for water main failure forecasting (Asnaashari et al. 2013) have been considered, while St. Clair and Sinha (2012) review water pipe asset monitoring models and estimates have been made for the benefits provided through pressure management in water networks (Gomes et al. 2011). While smart water remains at an emergent stage, data from a variety of field trials and utility scale deployments are now available. These data will be examined in some detail in the main text.

Jägermeyer et al. (2015) reviewed the potential for water savings in irrigation by moving from surface to sprinkler or drip systems as well as improving crop yields. Jägermeyer et al. (2016) identified a potential 62% reduction in the water-yield gap and an increase of global production by 41% through integrated irrigation management. Actual field trial data are considered in the section ‘reinventing irrigation’ below.

Looking further ahead, the first volume of ‘Smart Water: International Journal for @qua—Smart ICT for Water’ (ISSN 2198-2619) will be published by Springer (open access) from the end of 2016, meaning that smart water will have a dedicated peer-reviewed journal.

6.3 Water Megatrends and the Need for Smart Water

Water scarcity is a megatrend being driven by population growth, urbanisation and rising *per capita* consumption as people gain improved access to water services and the ability to acquire consumer goods. The global population is forecast to grow from 7.3 billion in 2015 to 9.7 billion by 2050 (UN DESA 2015) with the percentage living in urban areas rising from 53.6% in 2015 to 66.4% by 2050 (UN DESA 2014). Renewable surface water resources in accessible areas are estimated at 14,100 km^3 (Postel et al. 1996), compared with total water abstraction of 3829 km^3 in 2000 (Molden 2007) including 2810 km^3 from surface waters. As rainfall and surface water flow is neither evenly distributed spatially or temporally, water scarcity or stress occurs in areas where resources are inadequate in relation to the number of people living there.

Water scarcity has traditionally been defined as where renewable resources per person are below 1000 m^3 *per annum*, with extreme scarcity occurring when below 500 m^3 *per annum* (Falkenmark and Lindh 1976, 1993). The European Environment Agency (EEA) sees water stress starting at 20% of renewable resources being abstracted annually rising to severe stress when abstraction exceeds 40% (EA/NRW 2013).

16% of the global population lived in areas of water scarcity or extreme scarcity in 1980, rising to 35% by 2005 (Kummu et al. 2010). 36% of people were identified as living in areas of severe stress in 2010, which is forecast to rise to 52% by 2050 (Veolia Water 2011). The impact of population growth will be exacerbated by climate change and improving access to water in turn driving *per capita* water consumption.

In practical terms, these definitions are open to debate, since the way water resources are managed can have as great an impact on actual scarcity as water availability. While Singapore is officially classified as severely stressed and facing extreme scarcity, in reality its water supplies are very secure.

At the same time, water and wastewater networks need investment both to meet these changes and to continue to operate effectively. While most networks in developed economies are in reasonable condition, some are deteriorating. For example, the Report Card for America’s Infrastructure by the American Society of Civil Engineers rated drinking water infrastructure at D and wastewater D+ in 1998 (‘D’ equates to poor), both falling to D− in 2005 and upgraded to D in 2013 (ASCE

1998, 2005, 2013). In developing economies, the medium revenue per m^3 for municipal water delivered to domestic customers was US$0.81 in 2010 against operating costs of US$0.75 (Danilenko et al. 2014), meaning that capital investment is dependent on external funding.

The gap between current levels and necessary of capital expenditure is significant. In 2010 utilities spent US$173 billion on capital projects compared with US $384 billion *per annum* needed to maintain assets and services at their current level and US$534 billion *per annum* to secure supplies and meet currently foreseen standards and demands (GWI 2011). A particular challenge is the lack of political and popular will to increase tariffs to fund further capital work. A shortfall of US $52–115 billion *per annum* for projected revenues and anticipated spending in 69 countries nations between 2010 and 2029 has also been identified (Lloyd Owen 2009).

Smart water approaches can ameliorate these megatrends by (1) assisting consumers to modify their water usage, (2) improving the operational efficiency of water and wastewater assets, (3) avoiding the development of surplus assets, and (4) improving the resilience of water assets and other infrastructure to extreme weather events. For domestic and industrial customers, effective tariff and shadow pricing strategies are important tools in enabling these responses to take place.

6.4 Demand Management and Modifying Consumer Behaviour

In contrast to the traditional approach of seeking to provide as much water as customers need (supply management), demand management aims to modify customer behaviour to minimise water consumption so that it can be sustainably abstracted from extant supplies. Smart water enables the effective deployment of demand management through providing the consumption and cost information users need to modify their water usage. This is usually linked with at least a measure of cost recovery in the tariffs charged, so that users are financially incentivised to minimise their water use. The greater the financial incentive to minimise water consumption, the greater the incentive to ways of lowering water use through, for example, water efficient devices (domestic users), water reuse (water utilities and industrial users) and soil moisture monitoring (irrigation).

Full cost recovery for services (tariffs covering operating spending and financing capital spending) or sustainable cost recovery in some developing countries, (revenues from tariffs are blended with overseas aid funding (ODA), government grants, debt and cross subsidies) are necessary for consumers to be charged enough for their consumption behaviour to matter to them. Full cost recovery is being used in a number of countries including England and Wales, parts of the USA, Chile, Germany, Denmark and Australia, with water tariffs accounting for 1–2% of household income. Sustainable cost recovery is seen in some utilities in Brazil, the

Philippines, Macao, Cambodia and Namibia, with water tariffs accounting for 1–3% of household income (Lloyd Owen 2009).

The higher the domestic water costs and the greater the water consumption available to domestic consumers, the greater is the scope for their adopting domestic energy savings approaches. These include minimal water approaches for clothes washing machines, lavatories and taps, along with closed cycle showers and various grey water and rainwater reuse approaches.

In contrast to water utilities, industrial customers do not have the same regulatory, political or financial constraints when it comes to innovation. Their motivation is to adopt new approaches when it makes financial sense for them to do so, as well as in meeting their corporate social responsibility expectations. As a result, innovations can be take up more rapidly than is usually feasible for utilities and this may help to secure their commercial viability as well as acting as a test bed for their wider adoption.

Customer education is rarely considered, so customers are unable to appreciate how much they pay directly for water and sewerage services and how much is paid indirectly through taxation. The linkage between water consumption and the energy consumed to heat that water is also poorly appreciated.

The effective appreciation of customer behaviour was not until recently considered by water utilities. Increased customer and utility involvement in consumption and billing data requires the utility to understand how customers will view these changes. This includes being realistic about how much a price signal will achieve on its own (Smith 2015). Acceptance of metering is more likely to occur when it is part of a broader package of customer-related and water-saving initiatives, including cutting distribution system leakage.

Customer support is closely connected to education. 40% of customers surveyed by the Consumer Council for Water (a stakeholder body representing water customers in England and Wales) in 2008 supported compulsory metering, 25% opposed it and 35% were undecided. 60% regarded metering as the fairest basis for billing, 15% preferred rateable value and 25% were undecided. 60% supported more metering with 20% against and 20% undecided (Lovell 2016). The Consumer Council for Water also found that more than 50% of customers would reduce their water usage with smart metering systems if usage and price data was made clearly available and price comparisons were provided (Smith 2015).

Thames Water and Southern Water in the UK are rolling out compulsory smart water metering programmes. Thames has adopted a multi-stage approach, engaging with customers before, during and after meter installation to ensure they understand how to use them most effectively (Baker 2016). Southern is combining this with 58,000 household visits between 2010 and 2020 to advise customers about lowering water and energy bills and improving water efficiency (Earl 2016).

6.5 Metering and Measuring Water Consumption

Water metering is the foundation of domestic water demand management. Demand management is driven by the information each consumer generates and has access to, while water consumption savings are gained from each level of smart metering; the more information generated by the metering, the greater the potential for savings.

Manual meters record the cumulative amount of water passing into the property and require a physical inspection, typically once every six or 12 months. Advanced Meter Reading (AMR) allows a degree of granularity in data collection, storing readings for daily consumption for example, but the information flows from the meter to the utility only and requires some form of intervention by the utility to collect the data. This may involve a dedicated vehicle driving past the metered properties. Advanced Metering Infrastructure (AMI) allows two-way data transmission between the meter, the customer and the utility. Readings can be timed to suit each user's requirements; daily, hourly or even by the minute. As well as being a tool for the active influence of customer behaviour, it can be used to detect leaks at the individual household level and to detect anomalous usage patterns.

The more frequent the meter readings the lower the water use (186 litres/household/day with readings every 60 min and 138 litres/household/day with readings every 15 min) reflecting the greater granularity of the information available, allowing the customer to appreciate how their water is consumed and so alerting them to the potential for further water savings. Consumption also falls with time (175 litres/household/day after seven days and 162 litres/household/day after 30 days) from adoption, as customers respond to their consumption data (Hall 2014). Decreases in consumption are typically maintained where the customer continues to be informed about their water usage and its cost.

AMI metering has been introduced in countries such as the UK, the USA, Saudi Arabia, Israel, Malta, New Zealand and Australia. Three surveys in the USA found that the smart meter unit cost US$80–163, accounting for 28–66% of the total installation cost (EBMUD 2014; Sierra Wireless 2014; Westin 2015). Higher meter cost needs to be put in the context of longer term operating savings from no longer needing to take manual readings. Volume of manufacturing and installation scale and a greater practical appreciation of the benefits of smart domestic metering will be necessary for their adoption in developing economies.

Table 6.1 outlines the impact of manual metering in England and Wales during its gradual roll-out since 1990. Given that people who opt to have water meters will tend to be those who stand to benefit the most, it would be expected that the difference between metered and unmetered consumption would decrease as meter penetration increases. In fact, the reduction in water consumption was 9–10% in 2000 and 2005 and 18% in 2010 and 2015 while metering coverage rose from 14% in 1995 to 43% in 2015. In England and Wales, an earlier study found that demand was 9–21% lower after 'optant' meters were installed (at the customer's request) and 10–15% for compulsory meters (NAO 2007).

Table 6.1 Metered and unmetered household water usage in England and Wales, 1990–15

Litres/capita/day	Unmetered	Metered
1999–2000	149	135
2004–2005	152	138
2009–2010	157	128
2014–2015	151	123

Source Adapted from OFWAT (2000, 2005, 2010) and Water UK (2015)

Table 6.2 Benefits of AMR and smart metering

Benefit	AMR drive by metering	Smart metering
Gross benefits	£0.3 billion *per annum*	£4.4 billion *per annum*
Consumer benefits—bill savings	£11/household *per annum*	£40/household *per annum*
Water savings	40 million m^3 *per annum*	294 million m^3 *per annum*
Carbon reduction	8 million tonnes *per annum*	31 million tonnes *per annum*

Source Adapted from Slater (2014)

Table 6.2 compares the benefits of AMR drive-by and AMI smart metering (Slater 2014). AMR delivers a lower level of benefits at a lower cost than AMI. Four trials with smart meters in Australia since 2010 found a 10–13% reduction in water consumption compared with traditional meters (Beal and Flynn 2014).

Traditional metering reduces domestic consumption and this effect is more pronounced when smart metering is used. Metering traditional meters in the UK, USA and worldwide have resulted in 10–13% compared with comparable unmetered properties in trials and deployments between 1988 and 2000. Earlier surveys have shown appreciably larger reductions, but the data are now regarded as being unreliable. Where smart meters were installed at unmetered properties at Wessex and Southern Water in England in 2010–2015, 17% reductions were seen. When traditional meters were replaced by smart meters in Australia, Saudi Arabia and the USA, 7–15% reduction in household consumption was seen (Lloyd Owen, in press).

By linking smart water and energy metering, demand management can be redoubled as clients appreciate both sets of potential cost savings. Approximately 30% of household energy consumption is generated by heating water. Customers are typically more reactive to electricity bills than water bills and this becomes a proxy for modifying their water consumption. All households in Malta are being installed with smart water and electricity meters and data on the impact of this deployment is awaited (Pace 2014). It is also necessary for customers to have confidence in the potability and quality of their supplies, in order to end energy-intensive practices such as boiling piped water prior to drinking it.

The next level of integration is that between district and customer metering allied with dedicated leak detection systems enabling a utility to detect and manage leakage both at the household and network level. Household leakage, for example, is often unaccounted for, due to the difficulty in detecting low level leaks. By measuring night-time consumption at the household and district metering area (DMA) level, in real-time, household leakage can be identified and quantified. Smart metering also allows tariffs to be changed to encourage conservation at peak use times and drier periods.

6.6 Reinventing Irrigation

Smart irrigation approaches address the inefficient watering of crops and amenity land, by ensuring the greatest benefit is derived from the least water consumed. Water is only needed in those parts of the soil profile where roots are active and there is an evident need to avoid watering the soil when it is raining or at times of day when it less effectively used. Irrigation regimes can be realigned to optimising the soil moisture profile in relation to the ambient weather and root development. This also applies for amenity irrigation and in California and Texas, where parks, gardens and sports fields are mandated to adopt smart irrigation (OECD 2012).

At the simplest level, such as garden irrigation, this concerns a unit controlling irrigation flow and timing with a basic link to climate data. At its most sophisticated (for crops and vineyards), this involves soil moisture monitors that take into account soil types, soil compaction and the method of seeding, whether tilled or drill-seeded. One challenge is the decrease in ground station weather monitoring globally since the 1990s due to lowered government support. Local initiatives are being developed to redress this, such as the ‘Freestation’, a fully automated weather station, developed with low cost components and free software that can be installed by the grower for US$250.

Globally, 17% of cultivated land is irrigated and this produces 40% of the total crop yield. But irrigation is often wasteful, with 79% using the traditional flood irrigation method, 15% is mechanised, 2% is sprinklers and 4% is drip. Smart irrigation also uses fewer fertilisers and pesticides as well as less water, since their application can be synchronised. It also helps to avoid soil salination through minimising input and strategic soil flushing (White 2013). In market size terms, this is an emerging sector within the irrigation market. Sales of smart irrigation control systems were US$100 million in 2011, along with US$30 million for monitoring, US$10 million for ‘fertigation’ (combining fertiliser and irrigation) and US$70 million for greenhouse control systems.

A survey of irrigation management systems in the USA found 10–70% savings from 16 weather-based devices and 20–60% savings from four soil-moisture devices (US DOI 2012). Yields have also been improved by 10–40% due to improved root growth, avoiding over-watering and ensuring minimum moisture levels are maintained (OECD 2012).

In California, watering costs were reduced by 75% from US\$47,336 to US \$11,834 *per annum* for 900 growing avocado trees through soil moisture monitoring allied with automated irrigation. 44 soil moisture monitors were installed at a cost of US\$8200 into 22 irrigation blocks. One sensor is placed 20 cm down into the soil to measure moisture at the rooting level and a second sensor 60 cm down to ensure sufficient water is used to prevent salt accumulation. Savings are anticipated to ease to 50% when the trees are mature, but this remains significantly cost-effective (Water Active 2016).

As capital spending is needed both for the irrigation as well as the monitoring systems, a financial incentive is often required beyond purely improving the yield. Even so, where water is abstracted free in Spain, for growing strawberries, a free smart water management ‘app’, distributed by the beverages maker Innocent, has gained acceptance as it lowers pumping costs. Water consumption data was gathered by Innocent from 2010 to 2012 to quantify each grower’s water consumption and how consumption could be reduced while maintaining yield or quality. In 2014, the Irri Fresa ‘app’ was launched, which alerts growers when it is the best time to irrigate. Innocent’s participants reduced their water consumption by up to 40%, meaning that 1.7 million m^3 less water was used in 2015. During 2016, two other food brands and six retailers joined the Doñana Strawberry and Sustainable Water Management Group, with the aim of making water efficient growing the norm.

6.7 The Smart Sewer

Smart sewerage is at an earlier stage of development, yet its impact eventual may be of comparable size. The challenge for measuring sewage and other effluents is the presence of solids. Trials being carried out at Wessex Water (Wheeldon 2015) are circumventing this by using microwaves to avoid any contact with what flows within the pipes. These devices can detect flows of 0.02 litres per second, or 1728 litres per day and with real-time data, domestic usage patterns can be discerned. Therefore, as with smart water metering, the meter will be capable of identifying events such as a lavatory flushing, a bath emptying, a shower and clothes washing and dish washing machine cycles. This can be related to smart water data, meter enabling a utility to compare the daily volume of water supply, wastewater discharge and rainfall with each property. By comparing sewer flows during dry and wet weather, it is possible to determine which sewers actually handle stormwater, foul water and both. This can incentivise households and commercial users to maximise the use of rainwater within their properties and to employ ‘soft’ water soakaways (an example of SUDS, sustainable urban drainage systems) where rainwater percolates into the soil and the underlying aquifer rather than channelling rainwater through the sewer systems.

Smart approaches can prevent pollution incidents both from the discharge from the combined sewer overflow, ensuring that there are no overflows within the sewerage network, by Sewernet, a sewerage level network of monitoring and warning systems (Kaye 2015). The Sewernet monitors sewer flow within a system and relates this to the flow and capacity of sewage pumping stations, storm retention tanks and combined sewer outflows and to level, capacity and flow volume at the sewage treatment works, and quality and flow at consented outfalls. These can be related to current and forecast weather, and water flows in the allied distribution network. Another method for the early detection and prevention is based upon identifying blockages, polluting Combined Sewer Outflow (CSO) overflows and internal and external flooding (Woods 2015).

6.8 Minimising Non-revenue Water

Leakage both within the distribution network and households can result in significant losses in revenue and the wasteful treatment and transport of unused water. Domestic leakage detection is possible via the real-time detection of anomalous water use patterns. By measuring water volumes and maintaining optimal network pressure, network leaks can also be reduced. Major leaks and pipe bursts can be remotely located and addressed, while low level leakage is minimised by avoiding excessive network pressure. Smart networks can also eliminate false data and illegal connections.

Two recent examples in Portugal demonstrate this. Non-revenue water (NRW) at EPAL, serving Lisbon, fell from 14.0 million m^3 *per annum* in 2010 to 8.2 million m^3 *per annum* in 2013 and the system's Infrastructure Leakage Index (ILI) fell from 5.7 (C—medium) to 3.1 (B—good) during this time (Perdiagio 2015). As a result, between 2005 and 2014, 100 million m^3 of water was saved, along with saving €0.8 million in chemicals, €5.5 million in energy used and overall savings of €7 million over this period. This enabled EPAL to rationalise and defer investments, resulting in improved business resilience and easing the need to raise tariffs. EPAL carried this out through five stages: (1) identify and quantify water flow through the networks through DMA network segmentation and continuous telemetry monitoring; (2) generate data about the clients and the network, including its length, number of connections and pressure to quantify water loss; (3) develop selection criteria and performance indicators and analyse relevant data to decide on priority actions; (4) locate water losses to optimise leak control; (5) identify where repairs are needed and carry these out effectively.

A similar deployment at Aguas de Cascais saw NRW fall from 2.53 million m^3 *per annum* in 2012 to 1.87 million m^3 *per annum* in 2014 (Donnelly 2014). All data analysis was automated from 2012 and the size of the district management area was reduced and pressure management systems brought in. Leakage data is overlaid on Google Earth and sent to leakage management teams, with each leakage event given a unique identity and linked to the relevant before and after event data. The complete repair time (locate the leak, stop the water flow, repair and resume water supplies) fell from 294 min in 2011 to 236 min in 2014. The utility is now concentrating on optimising network pressure and predictive pipeline and asset management.

6.9 Lowering Capital Intensity

Water is a notably asset-intensive business, especially with regards to below-ground systems. In England and Wales, 2014–2015 revenues were 2.0% of the Gross Replacement Costs (GRC) of their assets and capital spending was 0.9% of GRC (Water UK 2015). This is equivalent to 110 years of current capital spending being needed to replace extant assets, let alone any new assets.

As a result, there is a need to ensure that all assets are actually needed and effectively used before any new assets are developed rather than replacing them according to untested assumptions or dealing with a deteriorating service. The need to develop new assets can be obviated by the effective use of extant assets through network and water use modelling, allied with demand management measures. Other approaches include optimising asset efficiency and operating life so that assets are only replaced when actually necessary rather than at a set date. For example, in Denmark, Copenhagen's HOFOR has an ILI score of 2.5, an efficient water network, despite 76% of its mains being over 60 years old and a 0.9% *per annum* replacement rate (Pedersen and Klee 2013). By using smart leak detection to detect them as early as possibly, the cost of leaks to their surrounding infrastructure is avoided, lowering potential damage by a factor of 50–200 (Fischer 2016).

An example is the Prediction of Discolouration in Distribution Systems model, which identifies most cost effective form of water pipe conditioning to use in six trials at Wessex and Northumbrian Water in the UK. Instead of planned work on 31 km of pipes costing £4.65 million, alternative approaches were identified at a total cost of £0.37 million (Boxall 2016).

6.10 Lowering Operating Costs

Improved efficiency through smart water and other initiatives has the potential to reduce operating spending in England and Wales by up to £1.8 billion (Slater 2014) against 2014–2015 operating costs of £8.7 billion (Water UK 2015). Table 6.3 outlines the various potential savings outlined in this survey. The energy consumption costs would mainly benefit customers rather than the utilities, through less energy being spent on heating water. A lower level of customer service costs has been noted in Portugal as leaks are repaired more quickly along with fewer and shorter service interruptions, and more prompt and accurate billing.

In each case, costs are lowered through increased data being generated in a more timely and specific manner, allied with the ability to act on that data in the fastest and effective manner.

Table 6.3 Operational benefits of smart and allied approaches in England and Wales

Reduced energy consumption	£1047 million (32%)
Leakage repair efficiency	£693 million (21%)
Customer service savings	£599 million (19%)
Recovered revenue (faulty meters)	£408 million (13%)
Reduced 3rd party liabilities	£318 million (10%)
Network monitoring benefits	£87 million (3%)
Improved demand forecasting	£64 million (2%)

Source Adapted from Slater (2014)

Global Water Intelligence (GWI) (2016) notes that smart water approaches have the potential to reduce capital spending by 12% for water utilities in 2016–2020. This includes 15% lower capital spending for drinking water treatment, water distribution and wastewater treatment and 8% for wastewater collection and drainage, or US$28.5 billion *per annum* overall. A 10% reduction in operating costs has also been identified, which would lower them by US$35.3 billion *per annum*, freeing these operating revenues to be used in developing new assets and service extension. According to GWI, the greatest potential for operating savings is in water and wastewater treatment, through for example, lowering energy costs by optimised pumping.

6.11 Benchmarking to Counter Corruption

Another aspect of efficient asset development and management is minimising the impact of corrupt practices. 10–40% of tariffs, grants and loans are 'lost' in countries where funding is at its scarcest (Transparency International/World Bank Institute 2009, Transparency International 2008). By being able to collect and interrogate as many forms of information as possible (bill payments and water usage, hardware procurement and operating costs) local and international benchmarks for best practice can be developed, reducing the headroom for corrupt practices to operate in.

6.12 Flood Management and Prediction

Traditional assumptions about the frequency and intensity of flooding events are being undermined by climate change. Parts of England experienced the most May–July rainfall in 250 years during 2007 (EA 2007), with a cost of £2.5–3.8 billion (EA 2010). The 2009 floods in England included the wettest 24 h recorded in the UK (Miller et al. 2013), while the 2012 floods across the UK included the wettest individual months from April–June since 1910 and the wettest April–June since records began in 1766 (Met Office 2012). Finally, the winter of 2015–2016 saw the highest 24- and 48-h rainfall ever recorded in the UK (Barker et al. 2016).

Flood resilience requires two approaches. As well as developing and deploying the physical infrastructure, there is a need to actually understand the nature of flood events from cause to effect, so as to prevent their taking place, minimise their impact, and to be able to predict them with as much warning tie as possible. In China, 30 'sponge city' pilot projects started in 2016, on top of 16 that started in 2014. These cities will use large scale SUDS projects in conjunction with conventional storm sewerage systems.

For surface water flooding this includes understanding each river basin's geomorphology, surface water flow patterns and the impact of man-made features on these, along with real-time soil moisture, groundwater, surface water and rainfall data monitoring and applying this information to previous events in a feedback loop to maximise warning about flood events and align flood mitigation and defences to threats.

In the case of sewer flooding this includes real-time data covering radar telemetry, rain gauges, water levels (sewer level monitors) and pump operation fed into a model to generate operational forecasts that trigger warnings via e-mail alerts and visual information. This provides advance warning of when pumping is needed, alerts if forecasted operations are not carried out, or if there are missing data inputs or divergence from the model occurs, allowing the operators to have a broad appreciation about operating conditions (Cockcroft 2015).

6.13 Smart Water and the Security of Future Supplies

As mentioned above, water scarcity is becoming increasingly widespread and intense. Most water consumption forecasts are based on the assumption that current approaches to water management and use will not be changed in the foreseeable future, a case of business as usual. For example, the UN Food and Agricultural Organisation (UN FAO) forecasts that a growth in demand of 3044 km^3 *per annum* between 2010 and 2030 will exceed renewable supplies of 4202 km^3 *per annum* by 2698 km^3 *per annum*. This is outlined in Table 6.4.

Such a shortfall could be made up via desalination and water reuse, along with the non-sustainable use of groundwater (above its natural recharge rate), but the cost would be substantial. Indeed, while the idea of using desalination for irrigation

Table 6.4 UN FAO water shortfall forecast

Water abstraction (km^3 *per annum*)	2010	2030	Shortfall
Municipal	434	900	429
Industrial	733	1500	703
Irrigation	2699	4500	1566
Total	3856	6900	2698

Source Adapted from 2030 WRG (2009)

Table 6.5 The cost of desalination/water reuse for meeting the 2030 deficit

Municipal shortfall	429 km^3 *per annum*	US$86–129 billion *per annum*
Industrial shortfall	703 km^3 *per annum*	US$141–211 billion *per annum*
Agricultural shortfall	1566 km^3 *per annum*	US$767–1645 billion *per annum*
Total shortfall	2698 km^3 *per annum*	US$894–1985 billion *per annum*

Table 6.6 The potential impact of smart water on water demand in 2030

km^3 *per annum*	Business As Usual (BAU)	Demand Management (DM)	Shortfall	Cost
			Net of DM	US$ billion
Municipal	900	600	129	US$26–39 billion
Industrial	1500	900	103	US$21–31 billion
Irrigation	4500	1800	0	US$0 billion
Total	6900	3300	232	US$47–70 billion

is somewhat extreme, it is a useful indicator as to the wider costs involved when irrigation water is underpriced. Water reuse is widely used as a source of irrigation water, typically with no treatment (Winpenny et al. 2010), which has public health implications.

On the assumption that the cost of mobilising new water resources via desalination (US$0.45–0.60 m^3 plus bulk transport where necessary) or water reuse (US $0.20–0.30 m^3) it would cost US$894–1985 billion *per annum* to make good this deficit, as detailed in Table 6.5.

Using smart water approaches for effective demand management are a pointer towards developing sustainable water management worldwide. Through reducing demand and improving service delivery and network efficiency, along with pricing policies that encourage such actions, the author believes that a reduction in water demand by 2030 from 6900 km^3 *per annum* to 3300 km^3 *per annum* is feasible as outlined in Table 6.6.

While there would be a continued projected shortfall for municipal and industrial water, there would still be adequate renewable resources for irrigation. This reflects the scope for savings when inundation is replaced by controlled irrigation. The higher prices charged for municipal and industrial water mean that alternative sources can be financially feasible.

6.14 Discussion

This is a tentative attempt to outline the provisional achievements of smart water approaches to date and their potential realisation. The very nature of smart water, fast evolving and seeking to become as user-centred as possible, means that its ultimate impact remains to be determined. Mobile telephony in the 1980s is a useful analogy as to how innovation does not necessarily develop as expected. This was a high value service launched in a number of countries between 1984–1988, which aimed to appeal to professional subscribers accounting for 2–5% of the population by 2000. Instead, mobile telephony has become an almost universal commodity service driven by applications for smartphones that were not mooted at the time.

Therefore smart water needs to be considered in the context of the uncertainty that lies in evolution of its technology and how people will desire it and use it. This is also driven by the inherent flexibility of smart approaches and their potential to be more open to addressing currently unforeseen applications and solving unexpected problems.

Smart water should not be regarded as a universal panacea for our current and impending water resource conflicts and challenges. Neither is it a technique that can be applied in isolation. Its chief benefits are as an enabler and an integrator for various aspects of water management. It is evident that the most of these approaches depend on the political will to charge appropriate tariffs and whereby utility companies are able to inform their enemies about their stratagems.

Challenges facing smart water applications include ensuring the security of Internet enabled devices and services and to develop interfaces with the customer rather that the developer in mind, along with building customer confidence in getting data flowing upwards towards the utility rather than just towards the customer. Smart ‘apps’ are of particular importance in reconfiguring the flow of data between communities and their administrators. Indeed, in developing economies, Smartphone ‘apps’ are becoming a tool for the local level reporting of safe water and sanitation connections, enabling community-level monitoring. In urban areas such applications will have profound implications for the early warning of non-supply, leakage, and sewer overflows.

Disruptive events are rare in the water sector: activated sludge for wastewater treatment (1913), reverse osmosis desalination (1965), membrane bio-reactors for water and wastewater treatment (1989) are the most prominent. While most smart water innovation is incremental, some may have a disruptive potential. A greater impact comes through synergetic accumulation of several minor improvements. This will depend on ‘monitoring the monitoring’ and implementing continuing-loop system optimisation allowing the incremental benefits to mesh together into larger scale improvements.

The megatrends affecting water resources and their use are going to require a fundamental change in how the water cycle is managed. Smart water approaches offer a suite of tools that can enable such changes to be delivered with an emphasis on minimising water consumption, improving service efficiency, securing resource resilience for the lowest environmental and economic cost.

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Chapter 7
Megatrends in Shared Waters in 2030 and Beyond

Melissa McCracken, Laura E. R. Peters and Aaron T. Wolf

Abstract Looking to 2030 and beyond, the future of shared waters is likely to have parallels with the present, but there is also likely to be expected and unexpected changes within shared water systems and their management. This paper identifies several trends—climate change, new technologies, and information availability and control—that will present both threats and opportunities to shared waters. Climate change may place unique stresses on shared waters by precipitating sudden, unpredictable changes in the hydrologic system that may exceed the institutional capacity to mitigate negative impacts of these changes. New technologies will provide ever-improving tools to view water as a flexible resource and aid in management, decision-making, and negotiation surrounding shared waters. Information availability and control raises questions about transparency and inclusion, and digital-physical security open shared water systems and associated infrastructure to vulnerabilities that may shift rapidly. The institutions governing shared waters will need to adapt to the threats and opportunities offered by these and other future trends. To aid in this effort, several shifts may be necessary in the understanding of shared waters—how shared waters are conceptualised, how inequities are embedded in management, and how shared water actors are broadening in scope. These shifts may support the development of adaptive and flexible institutions and enable them to anticipate and respond to uncertainties facing shared water systems in the future.

Keywords Shared waters · Climate change · Technology · Digital security
Water security · Adaptive management · Institutional capacity

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7.1 Context of Shared Waters

The dynamic nature of water resources inspires a future-oriented perspective towards increased water security and enhanced cooperation over shared waters. While water security definitions have evolved since the term first emerged, the most cited definition is ‘the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems, and production, coupled with an acceptable level of water-related risks to people, environments, and economies’ (Grey and Sadoff 2007; Cook and Bakker 2012). Water security becomes more complex within shared waters—waters that are traversed by political and social boundaries.

Most of the literature on water resources and management focuses on the basin scale as the natural unit for planning; the basin is defined by its hydrology, giving the perception of physically determined neutrality (Giordano et al. 2015). However, these physical boundaries do not always correspond with political boundaries. There are 310 international river basins and nearly 600 international aquifers that cross boundaries between two or more nations (IGRAC 2015; Wolf et al. forthcoming). Accounting for approximately 80% of the global river flow, international basins cover 50% of the global land surface (excluding Antarctica), and they are home to about 40% of the world’s population. Given the added sociopolitical and administrative complexity of rivers crossing international borders, there is great interest surrounding international river basins.

While much of the water conflict and cooperation literature focuses on international, transboundary waters, shared waters exist within state borders as well; basins within a state may cross subnational administrative boundaries, cultural boundaries, or social cleavages that do not coincide with international borders. Both international and subnational shared waters are under similar stressors to meet social, environmental and economic demands, but these stressors manifest differently depending on the spatial scale. It is critical that discussions of shared waters—including management, security, conflict and cooperation—address these differences of scale.

‘Water wars’ literature, especially public media and non-peer reviewed sources, has made assumptions that water scarcity can and will result in violent conflict over transboundary waters, including warfare between basin states. More recently, discussions have shifted towards climate change inducing potential war and violent conflict (Barnaby 2009); however, climate change’s primary impacts will be to water. Scholarly literature shows that states do not go to war over water even when facing changes in quantity or quality; interactions between basin states fall overwhelmingly within the spectrum of cooperation (De Stefano et al. 2010a; Yoffe et al. 2003). Similarly, within subnational basins, water users are more likely to cooperate than to engage in conflict (Eidem et al. 2012).

Despite the broad absence of violent conflict, water stress and competition among water users can induce and escalate existing political or social tensions. Conflicts over water resources—mainly nonviolent conflict such as heightened tensions or threats—are likely to gain in frequency, particularly at the subnational level, as resources become scarcer in quantity and degraded in quality (Delli Priscoli and Wolf 2009). Shared water disputes at a subnational level have greater potential for and intensity of conflict (Giordano et al. 2002). This is not surprising, given the much higher prevalence of civil conflicts than interstate wars over non-water related issues (e.g. Collier and Hoeffler 2004; Fearon and Laitin 2003). As water resources become less accessible or available, the impacts from one area's use will begin to have a greater effect on neighbouring users, increasing the potential for tension. For example, during drought conditions, an upstream user might increase their proportion of withdrawal to meet internal demand for irrigation, which would further reduce the water available to downstream users and could lead to political conflict.

Humans have been using, developing, and managing shared waters in a similar, yet evolving, manner for the last 5000 years (Biswas 1970). Despite the seemingly constant nature of shared water management, it is perhaps more accurate to say that water resources and the sociopolitical contexts and relationships surrounding these resources are always changing, and institutions must constantly adapt in order to effectively manage shared waters. Therefore, 'the likelihood and intensity of conflict within a basin increases as the magnitude or amount of change in physical or institutional systems exceeds the capacity to absorb that change' (Yoffe et al. 2003, p. 1117). This relationship between water and conflict, together with the institutional capacity to address the conflict, is particularly relevant for shared waters looking towards 2030 and beyond.

7.2 What Might the Future for Shared Waters Look like?

Shared water management in the future is likely to be similar to the present. For example, governments or water users within high-income countries have, and will continue to have, greater ability to adapt to change, while low-income countries—the Majority World—will not. Despite facing similar risks as low-income countries, such as hydrologic conditions, population growth, quality concerns, and other factors, high-income country investment in water services and infrastructure may reduce their threat of water insecurity. Communities, households, and individuals living in less wealthy regions with minimal investments in water technology, infrastructure, or comprehensive management strategies are more vulnerability to water insecurity. Currently, 3.4 billion people reside in regions that are exposed to high levels of threats to water security (Vörösmarty et al. 2010); of those, many are exposed to economic water scarcity or water insecurity not produced by physical scarcity but lack of financial resources (WBGU 2008). Additionally, subnational disparities between high-income communities, households, and individuals and those from lower income or marginalised groups can also lead to a wide gap in water security within shared waters that might be overlooked when considering a basin-wide scale. This disparity in risk between the wealthy and impoverished at the international and subnational levels is likely to continue or widen in the future.

Looking at trends in shared waters, such as climate change, new technologies, and information production and control, can provide a view into a possible future for shared water in 2030 and beyond. These megatrends present new challenges and opportunities, in addition to uncertainty, for shared water management, particularly when they are viewed in combination. Given that institutions must effectively adapt to reduce the potential for conflict, they must anticipate the challenges and opportunities presented by these trends in support of their short- and long-term planning.

7.3 Climate Change

Anthropogenic climate change is widely recognised as one of the greatest challenges to our generation, and it is projected to continue or escalate in future generations. While climate changes are far reaching, most of the impacts are experienced through the hydrologic cycle. Changes in weather patterns and environmental conditions add variability and increase the likelihood for extremes, affecting the quantity and quality of water resources (IPCC 2014). The main climate change impacts on shared waters will disrupt precipitation, temperature, and evaporation patterns (Ludwig et al. 2016). The spatiotemporal variability of these changes is expected to alter flow volumes and timing, groundwater recharge rates, glacial melt, and snow pack, as well as the propensity for drought or flood. In many shared water systems, climate change is experienced in combination with other stressors, such as population growth, economic development, environmental degradation, urbanisation, and inefficient agricultural and industrial practices. Climate change trends, coupled with added spatiotemporal uncertainty and other global changes, bring new risks and challenges to the management of shared waters. In 2030 and beyond, it is likely that climate change will present unprecedented stressors and uncertainty to institutions operating within shared water management.

Water resources management has historically attempted to overcome the natural variability of river systems by designing management and infrastructure according to historically observed hydrological records. This approach assumes climate stationarity, where future variability remains within historically observed bounds (Milly et al. 2008; Ludwig et al. 2016). However, the persistent and potentially severe climate change-induced disruptions to historical patterns reduce the ability of historical records to serve as a stable foundation for management planning and infrastructure design. This in turn undermines the ability of shared water managers to rely on past experience to make future-oriented decisions (Zeitoun et al. 2013).

Two factors are potentially more destabilising than the direct impacts of climate change itself: the rate of change and our inability to predict changes with spatiotemporal precision and at scales relevant for water managers. While some changes occur over greater spans of time, such as sea level rise, other changes may occur over shorter time scales, such as episodes of extreme flood. Climate studies indicate that changes in the hydrologic cycle and the rate at which they happen will likely be exacerbated by an altered climate (Michael and Pandya 2009; Svendsen and Künkel 2009). Climate science also projects long-term trends and predicts the magnitude and distribution of global variability providing shared water managers with a range of possible changes in their basin. These models, however, are less precise at subregional and short-term time scales (Allen and Ingram 2002; Moran 2011). Policy lenses operate within local scales and immediate to short-term focus, meaning that these models are not accurate to the degree needed—neither spatially nor temporally—for water managers or infrastructure designers to make decisions (Matthews et al. 2011; Ludwig et al. 2016). Short-term uncertainty about potential changes makes it more challenging to garner the political will to adopt costly climate adaptation measures. For example, much existing infrastructure will likely be rendered obsolete or inadequate to a changing environment, provided that the current predictions for climate change rate and scope are correct. Nevertheless, there is a great political and financial cost to constructing new infrastructure that address the eco-hydrological conditions in 100–200 years, especially when climate change scenarios cannot indicate certain changes to occur in specific timeframes or locations (Ludwig et al. 2016).

Biophysical impacts of shared water systems create secondary impacts on management, infrastructure and institutional conditions (Zeitoun et al. 2013). For example, regions expected to receive less precipitation will likely experience greater water shortages and competition between water user groups, which, in turn, creates management challenges or even potential political tension or conflict. California, for example, relies on natural storage in the Sierra Nevada snow pack to supply freshwater during the drier parts of the year, which coincides with times of peak demand. California's water management, particularly its water allocation system and infrastructure, was developed based on this timing and the reliability of this snow pack, but biophysical impacts from climate change are predicted to reduce the snow pack and alter the timing of peak flow. The secondary impacts will be to the state's water rights management and allocation system, which will be threatened and potentially rendered ineffective. The complex system of dams and canals to store and transport snow melt in the summer months could also become limited in functional capacity, given that it was not designed to accommodate the altered flow timing and greater volumes in wetter months. The state's urban population and agricultural sector is dependent on this system; therefore, a reduction in water resources combined with an inefficient management and infrastructure system will likely create competition between agricultural and urban users, with tertiary impacts on food price and availability where California produce is exported throughout the country and world.

Since political tension and violence become likely when change exceeds the rate of institutional capacity to absorb the change, the potential increased variability and uncertainty due to climate change will put greater stresses on the hydro-political system and complicate existing shared water management (Dinar et al. 2015). When compared to flexible and adaptive management regimes, sudden, unpredictable changes within a more inflexible supply-side management system based on historical patterns and not future models will likely trigger greater negative effects, including political tension (Zeitoun et al. 2013; Nardulli et al. 2015).

The global distribution of climate-driven risks is not uniform at multiple levels. Politically unstable regions that lack the capacity to absorb these changes and those that are more economically reliant on climate-sensitive resources, such as primary resource commodities, will likely feel the greatest impacts of climate change (Barnett and Adger 2007). At a subnational level and regardless of state-level development, marginalised communities and individuals are disproportionately exposed to and impacted by climate change (IPCC 2014). Due to the existential nature of water, there will be increasing pressure on shared water managers to make equitable decisions in a climate of uncertainty. Further, this pressure will likely be politically charged, as '… climate politics is like all other politics; it is partly about what is real and partly, sometimes predominantly, about what is believed, expected, and feared' (Moran 2011, p. 5). As climate change drives more acute and protracted water resource disasters, the impacts will differ depending on how these crises are perceived by the public. If impacts are perceived to be focused on marginalised groups, management and institutions may not respond as adaptively or effectively to mitigate impacts as compared to potential impacts on non-marginalised groups. Furthermore, institutions serving marginalised groups may lack or have reduced capacity to mitigate impacts regardless of perception.

7.4 New Technologies

Changes in shared water management historically have occurred through improved hydrologic understanding. Within the twentieth and early twenty-first centuries, advancements in technology have substantially enhanced understanding of hydrologic, social and environmental systems, which, in turn, has increased institutional capacity to manage these intersecting systems. This trend is likely to continue in 2030 and beyond as new technologies are created and refined.

Major technological advancements have been made to increase water supply and quality. In many high-income countries, wastewater reclamation for non-potable use has become commonplace. However, recent and future improvements in purification technologies have, and will continue to make, indirect and direct potable reuse more financially viable, particularly when compared to alterative supply sources or more energy- and/or cost-intensive treatment processes (Abrams 2015). Singapore's NEWater campaign, California's Orange County Water District's indirect potable reuse Groundwater Replenishment System, and Texas's direct potable reuse program in Wichita Falls are examples of new supply-side water management technology implementation. Challenges to widespread implementation include mobilising financial resources to cover the cost, overcoming the psychological aversion to toilet-to-tap water, and devising comprehensive, transparent regulation to ensure water quality. Potential future technologies and regulatory systems will take a step forward to assuage public concerns and make the technology more acceptable.

Of the many supply-oriented technologies, desalination stands to have a significant impact on managing shared waters. While desalination is an energy-intensive, costly process, it has been used for several decades as a solution to generate potable water in water-scarce, high-income countries with access to low-cost energy. Desalination is used primarily to supply drinking water to coastal populations situated at low elevations or in areas with no other perceived alternatives. Advancements in desalination technologies, such as improvements to reverse osmosis, have significantly reduced costs, making desalination more attainable to countries without access to cheap energy (Reddy and Ghaffour 2007). Future improvements will reduce financial constraints that limit wider use. For example, a reduction in desalination costs could expand brackish groundwater use as an alternative source in areas where it might be otherwise cost prohibitive to treat to a potable quality.

Combined with innovations in green energy technology or decreases in energy cost, the economics of desalination could profoundly change in the future. Solar powered desalination is currently more expensive than traditional energy, but the cost has been dropping dramatically—a trend likely to continue. The United Arab Emirates and Saudi Arabia are taking advantage of new solar technologies by opening several new solar-powered desalination plants for domestic consumption within the next few years (Martin 2016). While current desalinated water prices are generally affordable only for high-income urban water users, if the future cost of desalinated water lowers to agricultural water prices, a large proportion of agricultural water demand would shift to the sea. This shift is probably far beyond the near future, but desalinated water costs could lower sufficiently to supplement a larger proportion of the domestic supply to coastal cities, reducing competition between shared water users of freshwater resources. With respect to international shared water management, lower desalination costs could alter existing power dynamics between upstream and downstream riparians. Upstream riparians tend to possess inherently more power in negotiations than downstream countries, given their control of the headwaters. However, desalination capabilities may disrupt this power structure by offering some water independence to downstream countries (Aviram et al. 2014).

In addition to more traditional supply-side management, there is a trend towards managing demand. Shifting trends in management are paired with demand-reduction technologies, such as irrigation efficiency tools, low-flow utilities, and plant genetic modifications. Together, these new technologies will continue to provide major advances in reducing water consumption, thereby reducing the total amount of stress on shared water systems as they seek to satisfy competing demands between nations, communities, and/or other shared water users.

The demand and supply of high-resolution temporal and spatial data are expanding. With new advancements in technology, the cost of collecting hydrologic and meteorological data is decreasing, creating shifts in shared water management and negotiation. The ubiquity of wireless internet connections and satellite uplinks will improve monitoring systems and provide water managers with extensive watershed and climate data, potentially in real-time. New innovations have reduced the size and cost of weather stations, allowing for a higher density of stations that provide complete coverage and public access. Examples include the sensors designed as part of the Trans-African Hydro-Meteorological Observatory (TAHMO) project, which will collect hydrological and meteorological data across the African continent (TAHMO 2016). These high-resolution hydrological and meteorological data, particularly regionally detailed data, will help policy makers or shared water managers understand risk and uncertainty when estimating seasonal supply and demand for domestic, irrigation, environmental and other water needs (Hamilton 2012). In addition to centrally generated data sources, data collected through the assistance of the public, or crowdhydrology, may increase low-cost methods to collect data, such as stream gauge measurements. Crowdsourcing hydrologic data collection through cell phones is in its infancy, but it could provide supplemental data and public engagement (Lowry and Fienen 2013).

Remotely sensed data provide additional information on well-studied basins and on those that might be physically or politically inaccessible. High-resolution remotely sensed data are becoming ever more important in management and technical understanding of shared waters. For example, the high-resolution topography datasets collected through the Shuttle Radar Topography Mission (SRTM) or Light Detection and Ranging (LiDAR) allow for more precise delineation of watershed boundaries—which helps to identify shared waters—and create more accurate hydrological models of these basins (Farr et al. 2007). Future sensors similar to the current Gravity Recovery and Climate Experiment (GRACE) will expand the ability to measure changes in the Earth's gravity and will be used to estimate groundwater storage change more accurately (Joodaki et al. 2014; Powell 2012). The GRACE-Follow On mission and the Surface Water and Ocean Topography mission are two examples of upcoming remote sensors that will provide more detailed data on groundwater and surface water changes, respectively (Nelson 2016a, b). Water managers can use real-time and remotely sensed data to make decisions, such as water allocations for irrigation or reservoir levels for flood control, based on existing hydrologic conditions rather than fixed quantities or limited models based on historical data. Access to these data would further allow for non-stationary decision-making in the face of uncertainty and risk from climate change within shared waters.

Looking towards 2030 and beyond, advancements in modelling and data visualisation of future water resources will make information more comprehendible to decision-makers and allow them to consider multiple possibilities within dynamic systems. High spatiotemporal resolution of remotely sensed data will enhance geographic information (GIS) and modelling systems. Currently, hydrologic models are beginning to address groundwater in conjunction with surface water (Zeitoun 2011). Future watershed models will increasingly include groundwater, particularly as demand and stress on groundwater resources intensify. Within negotiation processes, future models and GIS serve as facilitation tools to improve cooperation and joint knowledge of a shared water system, where user groups, managers, or negotiators work together to cooperatively construct models and see the potential outcomes of various water policies or water infrastructure projects. Further, decision-makers will be able to examine the viability of proposed solutions with finer detail and accuracy, while considering expanded options in negotiations over shared waters, which is often key to successful negotiations (USACE 2006; Cole and Crawford 2007). Advancements will also allow participation of a wider range of actors and public access in support of transparent management.

Detailed and future-oriented information can be used to address problems within shared waters, such as limited water availability amidst competing demands from water users, that are made even more challenging when combined with population growth, climate variability, and regulatory requirements within an expanded spatial and temporal scale of management (e.g. water management adopting a long-term perspective on basin-wide issues) (Simonovic 2000). Technological advancements may help to encourage a greater level of data transparency between co-riparians, with a future goal of achieving hydro-harmonisation—or seamless hydrologic data on shared waters. Hydro-harmonisation will improve understanding and management through consistent data available to all shared water parties and the public, increasing transparency and awareness. The USA and Canada, for example, are working to create hydro-harmonisation across the shared basins along the US-Canadian border (IJC 2014; Laitta 2010). This trend towards technological advancements and adaptation of these technologies within management and negotiation may allow for future robustness and flexibility in shared waters management, while presenting an equalising effect with respect to power differentials due to data access.

7.5 Information Availability and Control

In addition to trends in water technologies, advancements in information and communication technologies (ICT) exponentially expand our ability to generate, store and share data and information with tools that will continue to be cheaper, faster and easier to use. Data become information when they are processed and organised in a way that allows individuals or groups to draw conclusions (Ehrlich et al. 1999; Timmerman et al. 2000). While improvements in data and information production advance the technical capacity of various stakeholders to make optimal decisions about complex water resource problems, issues surrounding data and information production, control of information, and digital security threats will present increasing challenges to shared water management.

Despite our improved technical understanding about water resources, our ability to manage shared water has not improved proportionately (Sumer 2014). This discrepancy relates to meeting often-competing water use demands associated with sustaining basic human life, food production, and environmental and industrial needs across sociopolitical divides. Further, different water user groups may not hold the same values guiding decision-making, such as prioritising water uses or temporal scale of management. As such, shared water resources management will continue to be confronted by complex problems, which can be described as 'ill-defined, ambiguous, and often associated with strong moral, political, and professional values and issues' (Islam and Repella 2015, p. 4). Complex water problems cannot be managed solely through scientific and engineering approaches, which offer solutions in isolation of the sociopolitical environments through which water resources flow.

To address complex water problems, critical questions rather than technology must drive the inherently subjective information production process, including deciding how to frame problems, what data to collect, how and when to collect it, how to analyse and interpret it, and how to present it. If the guiding questions do not encompass the complexity of the intersecting social-environmental systems, the information produced will not inform integrated and sustainable water management practices. The questions that are asked or left unasked may have far-reaching consequences on decision-making. For example, if only certain marginalised communities are situated on flood-prone land and questions refer only to wealthier, higher elevation communities, it is unlikely that water managers will reach equitable decisions. Additionally, perceptions of biased decision-making may undermine trust across sociopolitical divides, further weakening cooperative processes and peace.

An inclusive and transparent information production process driven by critical questions can lead to superior information, improved decision-making, and enhanced trust and cooperation. Including all water user groups at all stages of the process may provide a foundation for high-quality information that is trusted and relevant (Sumer 2014). This approach may also facilitate the generation of win-win solutions and promote trust-building across divides. Moving towards this ideal, there is a rising trend towards data and information sharing in all geographic regions of the world, including communication and notification systems; more than 40–50% of all current international transboundary water agreements have a mechanism for data exchange or information sharing (Giordano et al. 2013; Gerlack et al. 2011). Additionally, an increasing amount of both raw data and processed information on water quantity and quality are open to the public (Bruch 2005), which promotes the inclusion of non-state actors in shared waters decision-making processes. Shared water managers may build upon these trust-building mechanisms by innovating increasingly participative, real-time means for engagement and dialogue.

Despite research indicating that data and information are being shared with increasing frequency, water managers often conceal salient facts and findings from the cooperative process. Data control may be both a signal and a source of low trust and cooperation in a shared water system. Co-riparians with a history of mistrust or lack of cooperation may not embrace total data or information sharing (Sumer 2014). Often, the regional hydro-hegemon has greater access to data than is shared, as seen in the Ganges River basin where India uses data sharing as proof of cooperation, but Bangladesh's perceived lack of access to data has forced the state to push for further water data sharing (Zeitoun and Mirumachi 2008). States or water user groups that have control over data and information have greater control over decision-making processes, which appeals to hydro-hegemons or water user groups that benefit from an asymmetrical balance of power. In cases where data control or manipulation is detected by co-riparians or competing water user groups, it may further erode trust and willingness to cooperate over shared waters and potentially lead to heightened political tension or conflict.

Paradoxically, trends in ICT create tools for state and non-state actors to both engage with diverse water user groups and also maintain total or partial control of data and information. For example, encryption technologies enable individuals or groups to store and transmit data and information securely with algorithms that block unauthorised third-party access. For shared waters management, encryption tools provide pathways to engage selectively—or not at all—with co-riparians and water user groups. At times, this data and information control leads to degraded cooperation, but simultaneously, digital securities are becoming critical to the functioning and security of shared water management.

Management and operation of water infrastructure, such as dams or water treatment facilities, are moving towards automation and remote control through online systems that aim to increase management efficiency and precision. To combat the digital risks associated with online systems, network control systems increasingly use at least some form of digital security, such as two-step verification and firewalls. However, digital security is never absolute, because it depends on all authorised parties invariably adhering to strong security practices. Additionally, off-the-shelf or standardised management and security systems are cheap and easy to use, especially when paired with simple and unchanging passwords, but they are less effective at protecting systems from digital threats. If a single employee of a water management system uses an insecure password or falls victim to a phishing scam, an entire system may be exposed to risk from a malicious third party. Running in parallel with developments in encryption technologies are advancements in decryption and hacking, which enables third parties to covertly access, view, steal, and even alter or corrupt digital data and information.

Insecure or compromised digital systems expose water infrastructure to emerging digital-physical threats conducted by state actors, organised criminal groups, and even individuals. These threats include digital dismantling or unauthorised control of infrastructure, which could have profound impacts on water quantity and quality. For example, in a recently publicised case, Iranian nationals working for Iran's Revolutionary Guard Corps hacked into the Supervisory Control and Data Acquisition (SCADA) system of the Bowman Avenue Dam in Rye Brook, New York, in August and September of 2013. During the breach, they obtained information about water levels and temperature, and had the system not been offline at the time of access, the hackers could have gained access to the dam control system (Berger 2016). In another case, a former employee hacked into the SCADA system of Maroochy Water Services in Queensland, Australia, for three months in 2000 and released millions of gallons of raw sewage into the local rivers, parks and property, causing vast environmental damage (Gleick 2006; Smith 2001). Other means of disrupting or damaging water infrastructure include distributed denial of service (DDoS) attacks, ransomware, malicious software or viruses, or data erasure or manipulation. As the full range of adversaries expose more shared water system insecurities in the future and these events become publicised, interest and financial investment in mitigating digital vulnerabilities will grow even further. In 2030 and beyond, it is likely that shared water management will invest in more advanced digital security tools and practices, as well as full-time digital security professionals. While these measures can be costly and cumbersome, they provide a foundation for water managers to protect the water resources they oversee, the populations they serve, and the sovereignty of their management.

It is clear that co-riparians tending towards transparency and inclusion in the information production process will be much better poised to avoid political tensions. At the same time, shared water systems that employ robust digital security systems and practices will be less at risk for digital-physical threats. The tension between openness and security does not lead to simple solutions, and debates surrounding these issues will likely intensify in shared water systems with an asymmetric power balance or characterised by political instability.

7.6 Trends in Understanding Shared Water

Megatrends such as climate change, new technologies, and information availability and control will require us to reshape our vision of shared waters in 2030 and beyond. These megatrends present opportunities, challenges and uncertainties for shared water management. Further complicating our view, these megatrends are experienced in concert, which can produce unpredictable consequences. Additionally, the future will bring unforeseen global challenges and opportunities. While it is impossible to know precisely how shared water will look in the future, it is clear that shared waters management must acknowledge and grow alongside these megatrends. As a potential way to grow and bolster institutional capacity to adapt to changes, future management should acknowledge several shifts in understanding shared waters: (1) expanding how we conceptualise shared waters; (2) addressing inequities embedded within shared waters management; and (3) broadening the view of shared water actors. These shifts will strengthen shared water management's ability to generate creative and sustainable management strategies that respond to both short- and long-term challenges.

(1) **Expanding View of Shared Waters**: An expanded view of water as a flexible resource can increase water security (Islam and Susskind 2013), such as through new technologies creating alternative sources of supply. Furthermore, the economic capacity of states and shared water users can buffer the impact of water scarcity and prevent conflict over scarce water resources. For example, states that import water-intensive products such as grains are able to save water locally and use it to meet other water demands (Allan 2003, 2011), which can reduce pressure on shared water systems. There is direct evidence that virtual water trade of water intensive commodities, like grains, reduces water scarcity (Bhaduri 2016) and presents an alternative to competition and conflict over

shared waters. However, trade in most commodities is not determined by a comparative advantage in virtual water. The connection between virtual water trade and a reduction in water scarcity is also dependent on many other factors (Ansink 2010), meaning that trade in many commodities is not influenced solely by the amount of water available and therefore trade in some commodities may have limited ability to reduce water scarcity.

Given the capacity to trade virtual water globally, definitions of shared water as a watershed or groundwater aquifer that is intersected by an international or subnational boundary present a limited view of shared water potential. Basins may trade products with other basins and engage in a form of economic inter-basin water transfer. Therefore, trade and trade policy can influence water security in physically and economically shared waters, and water negotiations could discuss trade policy as part of a shared water agreement. Through trade, the import of commodities can obscure a water deficit that would otherwise be apparent if a national or local economy's water supply was required to produce all demanded foods and products. In addition to including economically shared waters, shared water understanding should include integrated groundwater and surface water systems to improve policy and decision-making that influence shared ground- and surface-water systems. An expanded view of the definition of shared waters potentially creates new solutions and creative opportunities within negotiations to reduce conflict and increase water security.

(2) **Addressing Inequities Embedded within Management**: Inequities may be embedded within potential solutions to shared water issues, and these inequities may exist at the international level between countries with differing financial or political power and also at the subnational level between communities, households, and individuals. If not addressed, an inequitable distribution of benefits and risks may lead to even greater inequity and degraded water security for marginalised states, groups, or individuals.

While the world is increasing its economic capacity as a whole, the lower economic capacity of certain states and water users can result in economic water scarcity. For example, Nepal experiences water scarcity because of its limited economy despite possessing ample physical water resources to meet its needs. While trade policies may offer potential solutions to water scarcity, they can also create a water deficit. Policies that create an economic comparative advantage in primary commodities in low-income countries will dictate the export of products that could be water intensive. For example, asparagus exported from Peru's Ica Valley to satiate demand in Western markets is rapidly depleting the region's groundwater resources and impacting the local people (Lawrence 2010; James 2015). These policies could create a cycle of exportation of high-value crops at the expense of local populations who may no longer be able to afford purchasing locally produced commodities with high nutritional content; further, these policies could work in favour of large agribusiness, reducing water resource access or availability to locally owned small businesses or local populations. Trade policies must consider their externalities on water security and inequitable social impacts.

Prioritising one state or water user at the expense of another will ultimately undermine the long-term security of an entire shared water system. Therefore, shared water management must address the structural violence underpinning the inequitable distribution of water in a shared system. While current and future advancements in new technologies provide a means to advance water security, the effect will be limited without a decrease in structural violence and inequity. Inequity with respect to water resources may be experienced at a state level (e.g. downstream or lower income countries), communal level (e.g. an indigenous or marginalised community), household level (e.g. socioeconomic or caste differences within a community), or even a sub-household level (e.g. societies where women, youth, or those with handicaps occupy a lower social status). Structural change is a difficult, long-term, and contextual process that must be driven by the involved parties. While social, political, and economic structures can be ingrained, they are recreated generationally and have latent capacity for positive change. The Majority World is generally well acquainted with calls to improve levels of equity and human development; however, high-income, developed countries are not exempt from this imperative to promote positive change towards more equitable management of shared waters at various scales.

(3) **Broadening Array of Actors**: The inherent connection between shared waters and other sectors will increase the number of actors that influence shared water management. These actors will include an increasing array of non-state actors at the subnational and international levels (e.g. local and international civil society organisations), international or multinational organisations (e.g. the World Bank or the United Nations), donor states and multinational corporations. Further, current trends in water research acknowledge that actors are not isolated within their sectors but are interrelated; for example, the water-food-energy nexus includes actors within the agricultural and energy sectors. In addition, non-traditionally water-related businesses and the financial industry are becoming actors due to the potential water-related risks to their business or investment. This broadening range of actors and sectors will potentially steer water management away from traditional approaches overseen by water resource experts towards more inclusive management within the greater sociopolitical environment (Zeitoun et al. 2013).

Engaging with a diffuse group of actors will result in opportunities and challenges. Participation of relevant actors in shared water management creates a sense of shared ownership and investment with the goal of generating creative options and alternatives in the face of conflict within the basin (Delli Priscoli and Wolf 2009). For example, water security and political stability may increase in basins that engage meaningfully and transparently with local citizens, consider best practices and technical assistance from international organisations, receive financial support from multinational organisations and/or donor countries, and initiate public-private partnerships. Further, cross-sectoral actors may be able to provide novel perspectives and alternatives not previously available within the basin. However, the inclusion of multiple third-party actors may invite a diffusion of new interests, including military, security, and economic objectives of non-riparian states or non-shared water users; these interests have the potential to be prominently represented or even prioritised in shared water negotiations. While shared waters management should aim to reflect this widening array of actors, they must also engage critically with local and global knowledge and perceptions to develop equitable management strategies.

Broadening these 'baskets of benefits' also allows for parties to pursue a path of enlightened self-interest where conversations on water alone may not have led. As we are seeing in South and Southeast Asia, for example, hydro-power generated electricity can cross borders readily, tying together countries that generate with growing markets of electricity users abroad. As issues on the table expand to include data-sharing, ecosystem protection, transportation, and flood management, networks of interests can broaden and strengthen across boundaries, as has been the case, for example, recently in the Ganges-Brahmaputra River Basin (Price and Mittra 2016). Similarly, governance in the Mekong River Basin expanded over the years, as the Mekong River Committee became the Mekong River Commission (MRC), to include the previously excluded Cambodia, but still only incorporating the four lower riparians. As dialogue became possible on more issues, the MRC was augmented first by the Greater Mekong Subregion, a development project of the Asian Development Bank that included all six riparians, and more recently by the Lancang-Mekong Cooperation Mechanism, a China-led approach working in parallel with its Bangladesh-China-India-Myanmar (BCIM) initiative, further cementing ties across South and Southeast Asia (Cronin and Weatherby 2014; Singh 2016).

7.7 Conclusions

Overall, shared water systems are experiencing both steady and punctuated change, and they will continue to do so looking towards 2030 and beyond. While change in shared waters has occurred throughout history, the magnitude and distribution of change—which is not limited to climate change—coupled with population growth, economic development, and other stressors, is increasingly placing pressure on surface and groundwater quantity and quality. Conflict over shared waters will likely change in 2030 and beyond; for example, quality will likely be a bigger issue than the available quantity of water. Subnational conflict driven by such issues as poverty, inequality and political instability is increasing, which may have direct and/or indirect influence on shared waters. Future research will need to more extensively consider subnational, transnational, and diffuse forms of conflict, despite the current emphasis on international conflict between state actors.

Cooperation over shared waters will also likely change in 2030 and beyond; for example, cooperation may extend towards the subnational direction, with citizen and non-state actor engagement, and also in the global direction, with the inclusion of multilateral and non-riparian state actors. Cooperation is not restricted by our definition of physically or economically shared waters. This opens the lens of what constitutes shared waters, as well as potential solutions to promote cooperation and mitigate conflict.

The root of water conflict and cooperation within shared water systems is dependent on the rate of change in institutions or within the physical river or groundwater system and the region's institutional capacity to adapt to these changes. Institutions provide formal and informal rules as well as structure to the interactions between shared water users, organisations, economic sectors, and other actors (Ostrom 2010). Past approaches to shared water management have focused on technocratic, supply-side solutions that limit institutional, particularly infrastructural, capacity to be flexible. Future shared water institutions will need to develop mechanisms to adapt to change and mitigate the impacts of these changes on their complex hydrological sociopolitical environments.

Adaptive institutions need to have the flexibility to adapt to rapid change and allow for non-stationary decision-making, while also provide stability in the long term. One key component of flexibility is the presence and quality of a water management body, such as a river basin organisation or groundwater management organisation. With respect to international waters, the number of river basin organisations has been increasing. There has been growing international support for their development, such as the World Bank's support for the creation of an international shared waters institution within Afghanistan (Malyar 2016). Further, the management body or agreement could contain mechanisms for clear water allocation, variability management, and conflict resolution (De Stefano et al. 2010b). Shared waters management must create long-term management plans that allow for uncertainty, for example, by building flexible infrastructure to endure a range of potential conditions.

The development of future technologies provides another potential means for adaptive management. For example, higher spatial and temporal resolution data generated in real time could allow for decision-making based on current conditions rather than historical averages. Technical information is often perceived as neutral and could play a role in supporting legitimacy and acceptability of solutions within shared water management (Nandalal and Simonovic 2003); however, technology is not a panacea, as it can promote a technocratic or Western perspective that overlooks or delegitimises local concerns and viewpoints that do not align.

Management that can adapt to current and future challenges will be better equipped to reduce vulnerability and address uncertainty in shared water systems within their sociopolitical environments. There will be many similarities between the shared waters of today and the future; there will also be different and potentially more complex challenges. Moving towards more flexible and adaptive management is a technically, financially, and politically challenging process, but it far outweighs the alternative. Future-oriented management that seeks to anticipate or respond rather than react to changes will likely result in more politically and physically stable shared water systems. Megatrends—climate change, new technologies and information availability and control—combined with shifts in understanding of shared waters may present opportunities to develop adaptive institutional capacity in pursuit of water security and enhanced cooperation between shared water users.

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Chapter 8
Megatrends in Hindu Kush Himalaya: Climate Change, Urbanisation and Migration and Their Implications for Water, Energy and Food

Aditi Mukherji, Christopher Scott, David Molden and Amina Maharjan

Abstract The Hindu Kush Himalaya is undergoing rapid change, driven by twin megatrends of climate change and urbanisation, which threaten their crucial water-provisioning services for over a billion people across Asia and undermine quality of life, economic development, and environmental sustainability within the region. This chapter examines current and future megatrends from a mountain perspective, assessing the impacts for water, energy and food security of glacial melt, altered river flows and drying springs, coupled with unplanned urban growth and outmigration. Further innovation is needed in responding to climate-induced risk, developing hydro-power sustainably and enhancing mountain agriculture.

Keywords Hindu Kush Himalaya · Climate change · Urbanisation
Migration · Water · Energy · Food

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8.1 Introduction

The Hindu Kush Himalayan (HKH) region (Fig. 8.1), covering 3500 km^2, stretching from Afghanistan to Myanmar, is a critical resource for Asia with its water, carbon stocks, energy potential, as well as its human, agricultural and biological diversity. Much of the world's irrigation is located just downstream of the HKH, and people are looking to hydro-power from the mountains to serve their energy needs. About 1.3 billion people in 10 major river basins rely on water resources emanating from the HKH Mountains and if we consider food and energy produced about 3–4 billion benefit indirectly from mountain resources. Mountain people have an important role to conserve this environment now and into the future. Yet in this region, ecosystems are fragile, and people, many who live in poverty, and many who are migrating, are quite vulnerable to climate and other changes.

The HKH region includes some of the poorest countries (Afghanistan, Nepal and Myanmar) as well as some of the fastest growing economies in the world (India, China). Moreover, the HKH mountains are shared by countries where there have been historical frictions and poor governance, leading to slow pace of development and poor developmental indicators. Global success or failure of the Sustainable Development Goals (SDGs) will partly depend on by how well these become implemented in the HKH region.

Forces on remote mountain systems have their repercussions downstream, across Asia and the world, and indeed the word 'mega' is appropriate to describe both potential magnitude as well as impact from various changes. A leading consulting

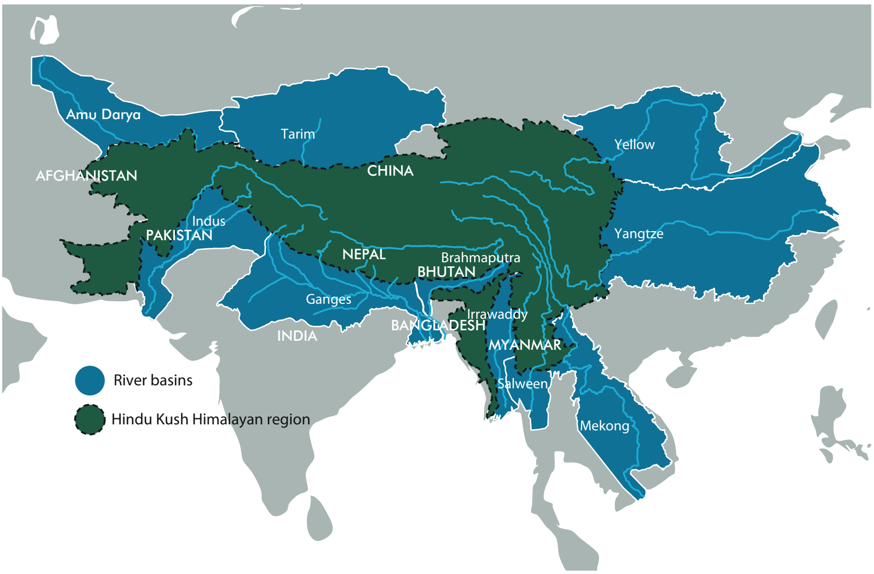

Fig. 8.1 Hindu Kush Himalayas (HKH) and ten river basins that originate from the HKH. *Source* ICIMOD

firm, Frost & Sullivan (n.d.), defines megatrends as 'global, sustained and macro-economic forces of development that impacts business, economy, society, cultures and personal lives thereby defining our future world and its increasing pace of change.' (http://www.baroriyan.com/Portals/0/mega%20trands%20exec%20summary%20v3%20(1).pdf)

This chapter presents the emerging megatrends in the HKH region and their likely impact on water, energy and food sectors in 2030 and beyond. The two most significant megatrends that are shaping the future of the HKH are climate change and demographic changes brought about by rapid unplanned urbanisation, of which migration (rural to urban within countries, between HKH countries, and globally) is the most important manifestation. Climate change is directly impacting glaciers, river flows and spring water supply, as well as agricultural production over mountain, hills and plains gradients. At the same time, migration and urbanisation are affecting the ways water, energy and food are being produced and consumed. The first section of the chapter sets the context of the HKH, the second and third sections describes climate change and urbanisation megatrends, while the final section speculates on the impact of these two megatrends on water, energy and food sectors in 2030 and beyond.

8.2 Hindu Kush Himalayas—The Water Towers of Asia

The HKH is referred to as 'the water towers of Asia' as the ten major rivers of Asia, namely, the Amu Darya, Indus, Ganges, Brahmaputra (Yarlungtsangpo), Irrawaddy, Salween (Nu), Mekong (Lancang), Yangtse (Jinsha), Yellow River (Huanghe) and Tarim (Dayan) originate here. The HKH region extends over 3500 km^2 west to east covering all or parts of eight countries from Afghanistan to Myanmar, and including Pakistan, China, India, Nepal, Bhutan and Bangladesh (Fig. 8.1). These ten large Asian river systems provide water, ecosystem services, and the basis for direct livelihoods to a population of around 210.5 million people in the HKH. Additionally, these rivers support downstream irrigation systems, provide urban water supply and ecosystem services, and control sediment processes and salinity dynamics while contributing to energy and food security for 1.3 billion people who live in these ten river basins (Immerzeel et al. 2010). The HKH is also called the Third Pole as it has the third largest store of ice and snow accumulation in the world (after the Antarctic and Arctic). The region has 54,252 glaciers with a total area of 60,054 km^2 and estimated ice reserves of 6127 km^3 (Bajracharya and Shrestha 2011), which are significantly impacted by climate change that disproportionately affects the high-elevation cryosphere (Shrestha et al. 2015a, b). Coupled with this, demographic changes such as urbanisation and outmigration (predominantly male) in turn are affecting the ways in which water, energy and food are produced, consumed and managed now and in the future.

8.3 Climate Change as a Megatrend

The climate in the central and eastern HKH is dominated by south-westerly monsoons with bulk of the precipitation occurring between June and September. There is a strong north-south gradient in precipitation due to orographic effects (Galewsky 2009 quoted in Lutz et al. 2016). Precipitation in the western Himalayas and Karakoram Range is influenced by both south-westerly monsoon and western disturbances, which means that in the western Himalayas rainfall occurs both in the summer monsoon season and in the winter. In some places such as the Karakoram, up to two-thirds of high altitude precipitation occurs in the winter (Lutz et al. 2016).

While it is certain that the HKH region is undergoing rapid change in climate, the exact extent of this is not known. However, we can recognise three overarching trends. These are: (a) a near universal agreement that temperatures are increasing, disproportionately so at higher altitudes (Bhutiyani et al. 2007; Lu et al. 2010); (b) variable future patterns of precipitation, which may increase, remain constant or decrease, depending on the HKH sub-region (Palazzi et al. 2015); and (c) some unanimity that higher rainfall intensity will occur in the core monsoon zone (Sharmila et al. 2015), while heavy precipitation events will increase in the Karakoram and western Himalayas due to increase in strength and frequency of winter westerly disturbance (Cannon et al. 2015). These trends are expected to lead to increases in extreme discharges in rivers (Soncini et al. 2015). Overall, this means that there will be more intense rainfall over fewer number of days, even though predicting extreme precipitation events is still methodologically difficult.

8.3.1 How Is Climate Change Likely to Impact Himalayan Glaciers?

Controversy and interest arose when the Intergovernmental Panel on Climate Change (2007) in its Fourth Assessment Report painted an alarming and somewhat erroneous picture about rapid melting of Himalayan glaciers. Cryospheric data in the HKH region was sparse in the early 2000s, and it was difficult to draw conclusions. Since then, more cryosphere-related work has been undertaken in the region and now we know that glaciers are retreating overall. An exception lies in the Karakoram range where it is reported that some glaciers are surging, while others are retreating, resulting in a near balanced state since 1970s (Bolch et al. 2017). This is called the Karakoram Anomaly (Bolch et al. 2012), which is thought to be due to increased winter glacial accumulation in the region (Tahir et al. 2001). Most glaciers elsewhere in the Indus basin have been retreating and losing mass strongly (Kaab et al. 2012. Glaciers in the Ganges basin are losing mass at a moderate rate ($\sim$0.3 metre water equivalent (mwe) year^{-1}, Kaab et al. 2012). However, glaciers in this basin are likely to be more sensitive to climate change since they experience accumulation and ablation at roughly the same time during the summer monsoon (Lutz et al. 2016). Glaciers in the Brahmaputra are either losing mass strongly (as in the eastern Himalayas ~ -1.1 mwe year^{-1}) or moderately (as in the Tibetan Platueau ~ -0.4 to -0.55 mwe year^{-1}) (Lutz et al. 2016). Overall, all the studies mention that there is some amount of uncertainty in glacier behaviour, particularly in the upper reaches (6000 m and higher) due to paucity of long term weather data at those high altitudes (Shea et al. 2015a).

Two important studies by Immerzeel et al. (2013) in Baltoro (Pakistan, upper Indus) and Langtang (Nepal, upper Ganges) and Shea et al. (2015b) in Khumbu (Nepal, upper Ganges) showed that there will be strong retreat, decline and loss in glacier volume by 2100. In another study, Lutz et al. (2014) showed that there would be declines in glacier cover by 20–48% in the Indus, Ganges and the Brahmaputra by 2050. So, overall, glaciers are expected to retreat throughout the rest of the century with clear implications for hydrological regimes downstream. However, all these studies suffer from a number of key limitations such as lack of long term and representative in situ observations, no consensus on common methods and above all, lack of high altitude weather data that make many of the future predictions uncertain (Lutz et al. 2016; Shea et al. 2015a, b).

8.3.2 How Is Climate Change Likely to Impact Himalayan Rivers?

How will melting glaciers and changing rainfall regimes affect flows in the Himalayan rivers? Himalayan rivers have varying dependence on glaciers. Lutz et al. (2014) estimated the contribution of glaciers, snow, rainfall and base flow to the total runoff for upstream basins of Indus, Ganges and Brahmaputra and found that glacier and snow melt are most important in the Indus; while rainfall contributes to most of the river flows in the Ganges and Brahmaputra. Similarly, Immerzeel et al. (2010) calculated the Normalized Melt Index (NMI), defined as the snow and glacier melt volume in a basin as a ratio of its downstream natural flow. This study assessed the relative contributions of glacier and snow melt water for the Indus, Ganges, Brahmaputra, Yangtze and Yellow rivers, with results ranging from 46% snow and 32% glacier contributions in the Indus to 6 and 3% of snow and glacier contributions in the Ganges. The generalised trends of west-to-east decreases in total annual precipitation and north-to-south decreases in glacial area and volume mean that rivers in the northwestern HKH have the greatest reliance on melt water, both annually over time and seasonally for summer-season flow.

Of the region's major rivers, the Indus has the greatest reliance on melting glaciers and seasonal snowpack, and the greatest contribution of glacier melt to the lean season flows (from March to May). Given the scarcity of long-term hydro-meteorological data from monitoring stations, reliable comparative studies depend on modelling. Zhang et al. (2013) compared model results for the Yellow, Yangtze, Mekong, Salween, Brahmaputra and Indus rivers and found approximately 80% of the annual flow in the Indus is derived from glacier and snow melt; while in the rest of the rivers, rainfall runoff accounts for most of the annual flow. However, except for Andermann et al. (2012), none of these studies looks at contribution of groundwater to total river flows. They estimated that groundwater storage in fractured bedrock of the Sapta Koshi, Narayani and Karnali basins in Nepal contributes 28 km^3/year (equivalent to around 20% of annual discharge)—double the amount of contribution of snow and glacier melt of 14 km^3/year.

It should be noted, however, that headwater streams and rivers close to glaciers and snow have a high dependence on melt water. Even in the southeastern HKH, glaciated high-mountain catchments still receive high proportions of total river flow from glacial melt. Many high mountain areas and communities are already impacted by this change. The threat is that mountain communities relying directly on glacier and snow melt will lose a significant amount of their supplies, which has already been documented in a few communities. There is also an increasing threat of Glacier Lake Outburst Floods (GLOFs) in communities adjacent to growing glacier lakes fed by increased glacier melt (Watanbe and Rothacher 1996; Osti and Egashira 2009).

Intra-annual timing of flow is important because glaciers tend to provide crucial summer-season flow for downstream irrigation, with a seasonal lag from precipitation that falls as snow in winter and melts in spring. Kaser et al (2010) estimated seasonally delayed glacier runoff relative to precipitation input across the HKH, concluding that the Indus has the greatest human dependence on glacier melt. Breadbasket regions in Pakistan’s Punjab province and India’s Punjab and Haryana states are also crucially reliant on March–May river flows, both as the source of irrigation water and to moderate the effects of soil salinisation, which becomes more pronounced in the dry season, and long-term aquifer salinity.

Recently, there have been a number of studies on long-term projections of total runoff, especially in the three basins of Indus, Ganges and Brahmaputra. For instance, Lutz et al. (2014) showed that there will be a consistent increase in runoff in the three basins at least until 2050. This will be due to increased glacier melt in the upper Indus and stronger monsoon dynamics in the Ganges and Brahmaputra. However, these trends are still uncertain given that future projections for precipitation, especially at higher altitudes, are highly variable. Similar results have been replicated in smaller catchments such as Baltoro (Indus) and Langtang (Ganges) by Immerzeel et al. (2013). In contrast, studies in the Hunza sub-basin (Indus) shows that while decadal mean runoff will remain constant, runoff in sub-basins will reduce drastically by up to 50% and increase in others (Ragettli et al. 2013). So, overall, total runoff is predicted to increase in the three major river basins, but with some spatial variations at sub-catchment level.

However, even more important than total annual runoff is the inter-annual change in flow, and this varies from one river basin to another. Lutz et al. (2014) projected changes in average annual hydrographs in six sub-basins of the Indus, Ganges and Brahmaputra and found that for the Indus, future water flows (2041–2050) remain comparable with the past flows (1998–2007); while in the Ganges and Brahmaputra, there will be increased peak discharge in the monsoon season and possibly reduced low season flows. In the Hunza sub-basin, in contrast, low season flow is likely to increase (Ragettli et al. 2013). So, overall, some changes in seasonal flow are expected; in some basins, this will lead to higher peak discharge and in others, to uncertain (higher or lower) lean season flow.

In summary, even though glaciers are melting, annual river flows will not be greatly affected in the medium term, but seasonal flows, especially pre-monsoon flows, in those basins will be affected. This is because snow and glacier contribution in annual terms is low (except for the Indus), but is significant in the dry March–May season. However, flows in mountain catchment areas close to glaciers and snow will be affected, having an impact on local communities. Despite high data uncertainty and spatial and temporal variability, climate change projections show that higher rainfall will compensate for declining snow and glacier contribution, but not in the dry season, so lean period flows may be further reduced, which is expected to have major implications for irrigation and hydro-power.

Perhaps more worrisome than glacier melt, but less understood, are changing precipitation patterns, and how this may lead to increased flood and drought hazards. As mentioned above, climate change projections show more uncertainty in precipitation, and more likelihood of extreme weather events, including intense rainfall events, resulting in more floods. The HKH region—both the mountains and the plains in the downstream are already susceptible to disastrous floods events such as flash floods including GLOFs and large riverine floods. This calls for an urgent need to understand the changing precipitation patterns on the one hand and equipping societies to become more resilient to floods on the other hand.

8.3.3 Drying of Himalayan Springs

While snow and glaciers are very important from a river basin and downstream perspective, in the highly populated mid-hills of the Himalayas, it is water from springs that sustains people by meeting their drinking, domestic and irrigation needs (Mahamuni and Upasani 2011). Springs also contribute to base flow of smaller streams, which in turn, join the main rivers that are sustained in the lean season by glacial melt. There is anecdotal evidence from all across the mid-hills in the Himalayas that springs are drying—and this could be due to climate change, tectonic activities (Sharda 2005), or even more importantly, local socio-economic changes such as road construction, land use changes in recharge zones, water intensive cultivation and so on. Tiwari and Joshi (2014) found that in their study area of 107.94 km^2 in Kumaon Hills in Uttarakhand, 33% of natural springs have completely dried, 11% springs became seasonal and over 736 km of spring-fed streams have dried mainly due to land use changes that led to decreased groundwater recharge. Other studies have also found that either springs have dried up completely, or their discharge has reduced or become seasonal (Vashisht and Sharma 2007; Vashisht and Bam 2013; Tambe et al. 2011; Valdiya and Bartarya 1989). Our current state of knowledge on springs in the HKH is very limited, similar to the lack of knowledge about glaciers in the early 2000s. It is therefore extremely important to build sound research on the hydrogeology of springs, and social systems that govern these springs. The International Centre for Integrated Mountain Development (ICIMOD) has developed an eight step methodology to study and revive springs using knowledge of hydrogeology and social science (ICIMOD 2017, under review) and it is being deployed in multiple locations for field testing and validation.

Overall, climate change is impacting glaciers, rivers and springs and therefore has important ramifications on future water availability for human purposes across a range of scales. Water supply megatrends, in turn, will affect future production of food and energy—with implications that we will dwell upon in the last section of this chapter.

8.4 Urbanisation and Human Migration as a Megatrend

The second megatrend is the rapid pace of urbanisation and outmigration in the HKH.

Like the rest of the world, rapid urbanisation is happening in the HKH region in response to multiple drivers. Rural urban migration is one of the contributor to the rapid urbanisation in the HKH region countries (World Bank and DRC 2016; Bhagat and Mohanty 2009; Muzzini and Aparicio 2013). There are various drivers for outmigration from the mountains including factors such as better employment opportunities, education, health, and related services in the cities (destination) and subsistence agriculture, land degradation and drying up of water sources (in the mountains). Urbanisation patterns in the mountains are inherently different from the plains due to differences in geography, and mountains rarely offer the kind of agglomeration opportunities available in the plains. In spite of geographical limitations, the reality is that urbanisation, most of it unplanned, is proceeding at a rapid pace in the HKH.

Overall, we can identify three broad trends in urbanisation in the HKH. First, in all eight HKH countries, urban population is increasing, while rural population will decline. By 2050, in six HKH countries (Bangladesh, Bhutan, China, India, Pakistan and Myanmar) more than 50% of the population will live in cities [UN Department of Economics and Social Affairs (UN-DESA 2014)]. In the other two HKH countries of Nepal and Afghanistan, urban populations are growing rapidly despite the projected demographic balance remaining less than half urban by 2050. Second, within mountainous parts of each country, there is a spatial variation in urbanisation with most of the urban growth happening in the valleys and in the mid-hills, while high altitude villages are increasingly de-populating. For example, in Nepal, of the 75 districts, as many as 23 districts have seen negative population growth from 2001 to 2011 and all of these are mountain districts. The districts in the mid-hills and plains have seen high population growth and Kathmandu city has seen double-digit growth during the same period (Central Bureau of Statistics 2001, 2011). In the Indian Himalayas, urbanisation has been much more rapid in the eastern Himalayas than in the central and western Himalayas (Indian Himalayas Climate Adaptation Programme (IHCAP 2017)) while in Pakistan, urbanisation has been more rapid in Baluchistan than in the Khyber Pakhtunkhwa Province (KPK) (Pakistan Bureau of Statistics 1998). Third, in some countries, much of the urban growth is happening in existing cities and towns (e.g. in Pakistan where not many new urban centres were added in KPK and Baluchistan, Pakistan Bureau of Statistics); while in some other regions, new urban centres are being added and erstwhile villages in peri-urban growth areas are getting re-classified as towns. For instance, in the eastern Himalayan states in India, 48 new towns were added between 2001 and 2011 (Population Census of India 2001, 2011).

These three trends lead to differentiated patterns in urbanisation across the region. However, what remains common across the region is that haphazard urbanisation has led to higher risks of environmental hazards (Anbalagan 1993; IHCAP 2017) and placed unprecedented stress on water resources in the urban centres. Most urban residents in the HKH do not get basic water and sanitation services from the government (Muzzini and Aparicio 2013). To fill in this demand and supply gap, urban residents either depend on rapidly deteriorating traditional water systems (Molden et al. 2016) or private water vendors (Raina 2016), with the poor often ending up paying more than the rich for water and basic services. Internal migration is leading to growth of urban centres in the Himalayas. At the same time, international migration is also picking up rapidly.

Internal migration is a common phenomenon across the HKH region. Internal migration as a percentage of the total population is about 30% in India (307 million as per Population Census of India 2011); 16% in China (221 million as per Population Census of China 2010, quoted in Liang et al. 2014); 14% in Nepal (3.8 million as per Central Bureau of Statistics 2011); 10% in Bangladesh (13.5 million as per Bangladesh Bureau of Statistics 2011); 14% in Myanmar (as per Fertility and Reproductive Health Survey 2007 (Nyi 2013). It is well established that outmigration from mountain villages is fairly common and is on the rise (Childs et al. 2014; Goodall 2004). Uttarakhand, a mountain state of India, is one of the ten major source states of internal migration in India (UNESCO 2013a). Recent population data from Uttarakhand show that many districts are witnessing negative population growth and there are over 1000 villages that have been abandoned (Pathak et al. 2017, forthcoming). A similar trend is also seen in Nepali mountains (Central Bureau of Statistics 2001, 2011). The major reason for this depopulation in the mountain areas is outmigration of entire families from rural to urban centres and these trends are seen in the Indian Himalayas, Nepal and Bhutan. Such rural depopulation patterns were also witnesses in European Alps, Japanese and South Korean mountain areas a few decades ago (Bätzing et al. 1996; Okahashi 1995; Choi et al. 2016). Internal migration can also be temporary, circular, seasonal and commuter migration. Official statistics often fail to capture this form of transient migrant population (Agrawal et al. 2015). Such transient migrant population are mostly involved in low-skilled and low-paying jobs and forms the most vulnerable

Table 8.1 Total population and international migration stock in 2013

Countries	International migration stock	Total population	% of total population
Afghanistan	5,632,196	30,682,500	18
Bangladesh	7,572,135	157,157,394	5
Bhutan	90,797	754,637	12
China	9,651,150	1,357,400,000	1
India	13,885,099	1,279,000,000	1
Myanmar	3,139,596	53,300,000	6
Nepal	1,986,203	27,834,981	7
Pakistan	6,170,411	181,192,646	3

Source World Bank (2016) (for column 2) and World Bank (n.d.) (for column 3)

group of population in urban centres with limited access to services, including water and sanitation (UNESCO 2013b).

Another pattern of migration on the rise is international migration. Table 8.1 displays the stock of international migration in the HKH countries.

International labour migration is also male dominated though, in recent years, female migration is on the rise. There are linkages between international and internal migration, as remittances send home by international migrants can help in internal migration of families from rural to urban centres (Martin 2009). Overall, it has been found that labour migration is an important livelihood and adaptation strategy (Gioli et al. 2014) for mountain people and often plays an important role in poverty alleviation (Lokshin et al. 2010; Hoermann et al. 2010). As such, migration as a livelihood strategy needs policy support (Grau and Aide 2007) and it is important to look into rural and urban development strategies in a cohesive manner.

Overall, the HKH region is witnessing rapid urbanisation and outmigration, and this has consequences for the way water is managed, food is grown and energy is produced, both in urban and rural settings. In the next section, we will first discuss the mountain specificity of the water-food-energy nexus in the mountains and then examine the possible impacts of the climate change and urbanisation/migration megatrends on water, energy and food in the HKH.

8.5 Implications of Climate Change, Urbanisation and Migration for Water, Food and Energy in the HKH

8.5.1 Understanding the Water-Energy-Food Nexus from a Mountain Perspective

While literature on water-energy-food nexus is abundant (Yang et al. 2016; Shah et al. 2012; Mukherji 2007), there are not many studies that look at this nexus from an HKH-wide perspective. One exception is Rasul (2014). Overall, while the nexus principle—that water, energy and food are interdependent and must be managed in an integrated way—remains valid, explicit attention to an upstream-downstream relationship is needed in the HKH. The entry point for understanding the nexus from a mountain perspective begins by acknowledging the crucial water-tower role of mountains, as elucidated above. From a mountain perspective, then, there are at least three different yet interrelated ramifications of the nexus.

The first issue is that of upstream-downstream linkages within a river basin context. Mountains are the source of water, which then flows downstream and is used for various purposes, the most important of which, for human purposes, is food production. Given the scarcity of land and uneven and often inhospitable terrain in the mountains—particularly with the second population and migration megatrend identified previously, mountains cannot grow sufficient food to meet their needs and therefore they must source food from the plains. The plains, on the other hand, derive energy security from the hydro electricity that is generated in the mountains. This energy is used for various purposes, including for pumping groundwater to grow crops. Therefore, the key issue here is: how to ensure that mountain communities are able to derive benefit from the services (water and energy) that they provide to downstream users. It is often the lack of fair systems of benefit-sharing (Shrestha et al. 2016) that leads to vociferous local protests against hydro-power dams.

The second issue is that of seasonality and the peaking of water and energy demand in the summer or winter season and excess water in the rainy season—in other words, the twin problems of too much and too little water. How does one meet the energy needs, of say, dry season irrigation in the plains at a time when river water levels are running low? One answer is hydro-power dams with storage. While runoff storage combined with power generation potential is indeed needed, the inherent fragility of mountain ecosystems together with high erosion and sediment transport rates compounded by seismicity in some parts of the HKH make dams environmentally problematic. Additionally, as noted, lack of sound benefit-sharing mechanisms makes them socially contentious. In this context, the nexus approach provides a less obvious solution. The transition zone between the mountains and plains (called the *bhabar* zone) happens to be an active recharge zone for groundwater (Siegel and Jenkins 1987). In the plains, just below this transition zone, say in the eastern parts of Nepal Terai and in Indian Bihar, there is a large unmet irrigation demand in the summer season, which could be met through using electricity produced upstream to pump groundwater in the plains. In the process, groundwater levels are drawn down in the summer season and the aquifer storage so created can be effectively recharged using monsoon flow (Revelle and Laksminarayana 1975; Amarasinghe et al. 2016). Again, this requires an integrated approach where surface and groundwater are conjunctively managed.

Finally, the third issue is meeting water, food and energy security at the local scale in the mountains. This calls for local solutions. The numerous community managed micro-hydro-power stations across the HKH bear testimony to local application of the nexus concept (Scott et al. 2016), but as we note later in this chapter, changing low-flow regimes in rivers will mean that many of these micro-hydro-projects may not provide viable, continuous power in the future.

Overall, Himalayan systems play a significant role in downstream agriculture and food security through their contribution to water supply, climate and flood regulation, groundwater recharge and sustaining wetland ecosystems. How will the two megatrends of climate change and urbanisation and migration affect future water, energy and food security? In the following sub-section, we speculate on some of these aspects.

8.5.2 There Will Be an Increase in Frequency of Water Induced Natural Hazards, but Better Technology, Governance and Regional Cooperation Will Ensure that Hazards Do not Turn into Disasters

In an earlier section, we noted that the monsoon is likely get stronger in the HKH, especially the eastern regions (Rajbhandari et al. 2016) and there is a greater likelihood of extreme rainfall events. With possible increases in extreme rainfall that occur along with glacier melt, the incidence and severity of water-induced hazards such as GLOFs (Ives et al. 2010), flash floods and riverine floods will increase. Coupled with the urbanisation megatrend resulting in greater numbers of people and density of settlements in the riverine plains and valley bottoms (IHCAP 2017), human vulnerabilities are expected to increase. However, whether or not such hazards actually result in disasters and cause loss of lives and property, will depend on how well local communities and national and regional institutions prepare for and cope with natural hazards. We take an optimistic view that that incidence of hazards actually resulting in massive disasters will diminish, as a result of advances in science and technology, coupled with renewed emphasis on traditional knowledge (Rautela 2005; Acharya and Poddar 2016), increasing government efforts aimed to avert disaster and increasing efforts to foster regional cooperation (Rasul 2014; Xu et al. 2009; Uprety and Salman 2011). We posit that it is advances in science and technology in the form of better computing capabilities and real-time flood information systems that will provide impetus for open data sharing and cooperation. Nevertheless, we recognise that creating regional environmental governance institutions can be challenging and will require sustained initiative and political commitment (Matthew 2012; Akanda 2012).

There are already impressive improvements in technologies for flood forecasting and early warnings—both at the level of community (Grasso and Singh 2011) and at transboundary levels (Shrestha et al. 2015a, b). Yet loss of life and property can result from institutional and governance failure, e.g. the Kosi barrage breach of 2008 (Gupta et al. 2010), where several warnings about an imminent breach were not conveyed to appropriate authorities due to top-down and archaic systems of communication. We argue that technologies that combine regional scale flood information with local level early warning systems are making rapid strides and will witness greater adoption. There is a very good likelihood that transboundary co-operation across upstream and downstream countries will mature, leading to open data sharing. This will also lead to better disaster preparedness. International frameworks for disaster risk reduction such as the Sendai Framework will also provide additional incentives to the national governments to cooperate around issues of disasters. Disaster management in Bangladesh is a prime example of how technology, communication and capacity building have been harnessed to reduce the impacts of natural hazards (Rahman et al. 2013). These good practices, which keep communities at the centre of their initiatives, can be replicated across the region.

8.5.3 Downstream Regions Will Have to Do More with Less Water

Low lean season river flows, coupled with increasing urban and upstream demand will mean that less surface water is available to downstream farmers for irrigation. At the same time, the higher intensity of rainfall over fewer number of days may mean lesser groundwater recharge in the *bhabar* zone and less water flowing to the plains below through regional groundwater flow. According to the only estimate available (Andermann et al. 2012), groundwater contributes to around 20% of annual river discharge in Himalayan rivers in Nepal. If the overall abstraction increases in the upper reaches or if there is lower recharge due to variable rainfall—as already evident through widespread drying-up of springs—then the groundwater component of river runoff will decrease, leading to reduced river discharge, especially in the plains downstream. The implications of this process are that water allocation for irrigation in the plains will decline. Whether or not it will lead to reduction in agricultural production will completely depend on how well technologies and institutions are able to adapt and produce more crop per drop (Molden et al. 2010). There is some evidence from irrigation systems in China (Kendy et al. 2003) that farmers have adapted well to drastic curtailment of water in agriculture and with the correct support (access to technology, credit and knowledge) farmers in other HKH countries can do the same. So, the prognosis here is that farmers in the plains will adopt practices that will help them grow more crops with less water. They will do so by adopting water-saving and yield-enhancing technologies.

8.5.4 Hydropower Plants Would Have to Be Constructed and Managed Differently Due to Changing River Regimes and Social-Environmental Demands

Hydro-power has already become the most important source of energy production in mountains, and this trend is likely to increase. The HKH region has a hydro-power capacity of close to 500 GW and almost all countries in the region have plans for expanding hydro-power in the future (Mukherji et al. 2015). But, for this to happen, while managing social and ecological controversies that surround hydro-power development now, there needs to be (a) norms for safe dam design and management of infrastructure, (b) better benefit-sharing norms (Shrestha et al. 2016), and (c) restrictions for development in sensitive zones. These norms continue to improve and we expect that by 2030, environmental and social impact assessment will be conducted and enforced, better and practical protocols for community-level benefit-sharing (Shrestha et al. 2016) will become as mainstream as protocols for safe dam design are today, and evidence-based regulations on targeted hydro-power development will be in place. However, the current trend for very small community managed micro-hydro-power may prove untenable because of low lean season flows (Yousuf et al. 2016). Shifting to higher capacity storage types of hydro-power may be inevitable—but they would have to go through proper environmental and social checks and balances, including equitable benefit-sharing mechanisms. So, the focus will be production of clean energy from hydro-power plants of small to medium size, while being cognizant of the clear limitations of very large hydro-power projects resulting from their high social and environmental costs, or very small projects due to hydrological flow uncertainty.

8.5.5 Increasing Outmigration from Hill and Mountain Villages, and Drying up of Mountain Springs Will Change the Contours of Hill and Mountain Agriculture

While outmigration and drying up of local water sources, especially springs will affect mountain agriculture (Poudel and Duex 2017), the way it will be manifested will depend on a number of factors. Depopulation in the mountain areas often leads to abandonment of agricultural land (Pathak et al. 2017, forthcoming; Jaquet et al. 2015). This will not only influence the local water use and food production but also the ecology. Abandonment of terraced farms in mountains after centuries of farming will lead to land degradation, as land abandonment does not automatically lead to re-generation of native plants (Harden 1996; Khanal and Watanabe 2006). Temporary labour migration, in turn, will lead to shortage of agriculture labour, particularly male labour and agriculture will become increasingly feminised (as they already have) (Maharjan et al 2012). If institutions do not respond to feminisation (as they are not right now), then mountain agriculture and irrigation systems will stagnate or even shrink. For example, many farmer-managed irrigation systems still depend on land-owner members, who are men and many of whom have migrated. So, women are rarely legal members and must depend on their husbands for day-to-day decisions conveyed to them through long-distance telephone calls. Under such circumstances, agriculture and irrigation systems will disintegrate rapidly as has already happened in parts of Nepal (Adhikari and Hobley 2015; Baniya et al. 2009) and in India (Negi et al. 2009). If, on the other hand, institutions do respond and become gender inclusive and women are able to make decisions (Kaspar 2006), and remittance money is invested in agriculture (Bohra-Mishra 2013), then, it is possible that the shift will become even more pronounced from rainfed cereals to remunerative crops such as coffee, orchards crops and mountain niche crops (Rahut et al. 2010). Such a shift, if it occurs equitably for women and disadvantaged communities, will mean economic prosperity, but this may or may not be possible everywhere if water is already scarce. Conversely, many governments in the region can provide incentives for mountain people to give up agriculture in return for assured incomes, for example, like the 'Grain for Green' programme in Tibet Autonomous Region (TAR) in China (Xu et al. 2006; Feng et al. 2005).

8.5.6 Increasing Urbanisation Will Put Stress on Newly Emerging Urban Centres, While the Older Urban Centres Will Upgrade Their Infrastructure and Install Sustainable Waste and Wastewater Management Systems

Rapid urbanisation is occurring across the entire HKH region. This means smaller district headquarters are becoming towns, while capital cities are becoming larger urban centres, stretched to provide adequate services. This is already putting unprecedented pressure on water resources in Himalayan cities because of growing urban population and concomitant increase in demand (IHCAP 2017). Urban centres in the HKH have traditionally depended on mountain springs, but many of these springs are drying due to a number of reasons, as stated earlier. In the future, it is very likely that larger cities will transport water through long-distance water transfers (Domènech et al. 2013). This is already happening in Kathmandu city, which is on the verge of importing 170 million litres per day (MLD) of water from the Melamchi river through a 26 km tunnel. Kathmandu valley faces a shortage of 210 MLD (Subedi 2010). It is also possible that some of these larger cities with better resource endowments will design suitable institutions for payment of ecosystem services for upstream communities (ICIMOD 2016). Experiments, such as willingness to pay for water services, have been conducted (Rai et al. 2016; Karn

2008) in Nepal and India. Similarly, while it is possible some urban centres in the Himalayas already have (Payment for Ecosystem Services) PES-like schemes to secure water from their forested hinterland, not many of these instances are documented. One exception is the case of Palanpur city in the Indian state of Himachal Pradesh, which has signed a reciprocal water access agreement with their upstream villages. This agreement is somewhat akin to a PES scheme and it seems to have worked for a decade now, even though the entire scheme is politically contested (Kovacs et al. 2016). It is likely that other urban centres in the HKH will take up similar PES models in the future. It is also likely that some of the bigger cities will invest in workable wastewater management and re-use solutions leading to a better water future. However, the real crisis will be in smaller emerging towns (like district headquarters), where there will be little investment to upgrade infrastructure or in suitable institutions due to paucity of resources. We argue that these smaller and medium towns and cities in the HKH will needed added attention from the policymakers in the region.

8.6 Conclusions

The two megatrends of climate change and urbanisation (and related outmigration) in the HKH will impact water, energy and food in the region in myriad ways. In this chapter, we have outlined some of the different pathways these megatrends may produce. Overall, challenges remain and much work needs to be done, particularly in mountain agriculture, urban water and wastewater management, and hydro-power development. Current trends show that, in majority of the cases, mountain agriculture will shrink further due to permanent family outmigration and the resulting land abandonment. Even when migration is male specific for labour purpose, lack of investment of remittances for improving agriculture, unless adequate policy measures are adopted in the very near future, will lead to shrinking of mountain agriculture. In numerous other contexts, however, including adaptive agriculture in the hills and plains as well as disaster preparedness, current developments in technology and governance make us optimistic. It is likely that even though extreme weather events and water-induced hazards will increase in frequency and intensity, improved technology and better management systems will pave the way for to mitigate those hazards. The key to improving all future outcomes is enhanced local decision-making supported by national programmes, data-sharing, and broad-based regional cooperation.

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Chapter 9
Shift in Water Thinking Crucial for Sub-Saharan Africa's Future

Malin Falkenmark

Abstract With large development optimism and seen as rich in water resources, Africa is—except for the humid equatorial area—an arid continent, dominated by vast savannas, which require skilful manoeuvring between unreliable rain, very thirsty atmosphere, sharpening droughts and low runoff generation. With a four-folding population and six-folding water demand in just 70 years, the pressure on the water resources is rapidly increasing and already approaching basin closure level in several regions. Since the *blue water* is concentrated to transnational river corridors, food production is 95% rainfed, i.e. depending on *green water* in the soil; subsistence farmers' yields remain low (some 1 ton/ha), and hunger is widespread. An African green revolution is slowly developing as a water harvesting supported agriculture, foreseen to allow even three-folded crop yields. Many countries cannot expect long-term food self-reliance, making national economic planning essential to secure an industrial development for generating necessary foreign currency. Africa's future is closely linked to its demographic changes, demanding due attention: both towards reducing extreme fertility; and to adaptation to the rapid expansion of middle-age population strata in response to growing life expectancy. Currently, two blindnesses are blocking the road to a sustainable future: city planners' lack of concern for megacities raw water supply; and the United Nations' (UN's) Sustainable Development Goal's (SDG's) total unawareness of green water's crucial role for hunger alleviation. Foreseeable water shortages will demand *water-security oriented policies*, based on blue water for urban, industrial and energy water supply; green water for food production; and widespread leap-frogging and water decoupling for manoeuvring water supply.

Keywords Africa · Blue water · Green water · Water scarcity
UN Sustainable Development Goals · River corridors

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Ingress
This article is a wakeup call for African leaders to be adequately aware and take urgent action to avert an entirely foreseeable danger of regional instability, conflict and outmigration linked to both demand-driven and population-driven escalation of water scarcity.

9.1 The Challenge

Africa is a continent dominated by drylands and a very thirsty atmosphere, leaving only some 20% of the rainfall to form runoff. Half of the countries are dominated by high-level poverty and hunger. This paper explains why conventional solutions addressing poverty and hunger used in Asia, relying on runoff water for irrigation, will not work in the vast dryland parts of Africa. Instead, direct management of scarce rainfall will have to be an integral part of the development agenda, a critical insight that seems absent in the proposed United Nations' (UN's) Sustainable Development Goal's (SDG's) hunger goal (UN 2015, goal 2).

The African Development Bank (2011) characterises Africa as one of the driest continents of the world, where savanna takes up almost half of the continent (Fig. 9.1), and hosts some 25 African countries that tend to remain low-income countries with widespread hunger and poverty. Agriculture is mainly rainfed and highly vulnerable to droughts, and the dry season typically lasts more than seven months. The continent is subject to three physical drivers of change: climate change, land use change/leasing and water under rapidly increasing pressure.

Currently, Africa's population density, although relatively low, is changing rapidly: UN projections indicate that the continent's overall population will more than quadruple before the end of this century (Gerland et al. 2014; UN 2015). Indeed, most of the world growth is expected to occur in Africa (Fig. 9.2). This fact is now raising increasing concern (Fisher 2013): '*The rapid growth itself will likely transform political and social dynamics within African countries and thus their relationship with the rest of the world*'.

In 2010, almost 500 million people lived in the vulnerable arid and semi-arid zones, and 245 million people in the dry sub-humid zone (Falkenmark and Rockström 2015). Rapid population growth will multiply these populations to altogether 1.1 billion in 2030 and 1.6 billion in 2050—another India! As a consequence, the region can be foreseen to suffer increasing difficulties of producing sufficient food for its expected population, in the long run making a sustainable future critically dependent on a sustainable food import. This will demand access to foreign currency, achieved by successful development of an export sector, building on low water-based industrial production based on accessible raw materials or other resources.

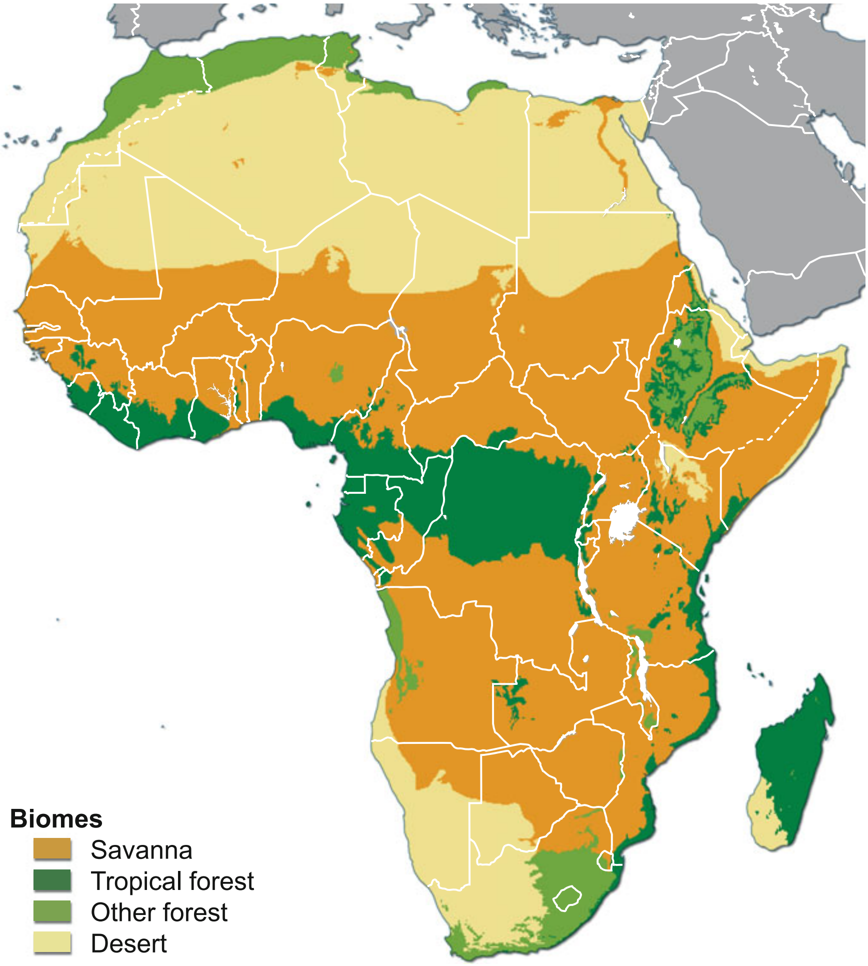


Fig. 9.1 Sub-Saharan Africa is dominated by tropical grasslands/savanna (based on Olson et al. 2001)

The continent's urbanisation rates are among the highest in the world, while '*the ability of African cities to cope with these numbers is questionable since they generally lack the institutional and infrastructural capacity to absorb the additional urban dwellers*' (Sturgis 2014). The State of African cities (UN-HABITAT 2014) stress that '*the massive population growth in a context of wide-spread poverty … generates complex and interrelated threats to the human habitat*'. Not much attention has yet been paid to potential implications of water shortage constraints to societal development, for instance, complications related to where to find the next generation of raw water sources to support the rapidly expanding multimillion urban populations (Falkenmark and Tropp 2016).

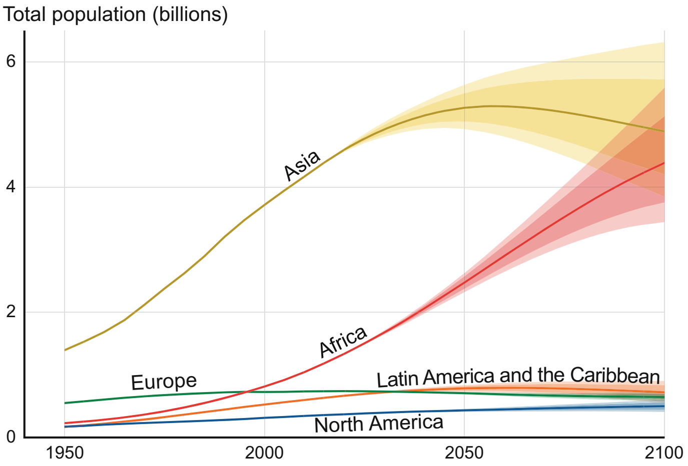


Fig. 9.2 Population growth this century is projected to occur at highest rates in Africa. Shaded areas indicate ranges for lower/upper projections (data from UN DESA 2015)

All these facts suggest that water awareness, strategies and policies will indeed constitute core elements on Africa's pathway to a sustainable future. Two fundamental water-related activities will be of particularly central importance for the future of Sub-Saharan Africa (SSA):

- secured *water supply* of the rapidly expanding cities foreseen already in this century, to be housing 70% of an overall population of four billion;
- water-secure *food production* for the rapidly growing population, most of which is living in the savanna-dominated region.

In this chapter, we will discuss the African megatrends with particular focus on the vast savanna region (Fig. 9.1), and the challenges of managing a situation of rapidly growing population.

9.2 Western Views Have Been Misleading

Many African authors have expressed concern over the dominance in past literature of conventional 'western views'. The fact that so little attention is given the issue of how to find safe raw water sources for booming multimillion cities suggests that, in spite of the massive scale, this issue may, in fact, have been seen as a purely technical task, like it has often been in the better water endowed developed world. Moreover, when it comes to the rapid expansion of food production, needed to feed the exploding African population, literature is dominated by the hope of rapid expansion of irrigated agriculture (African Development Bank 2011; Economic

Commission for Africa 2006). The South African scholar Turton (2012) has expressed the concern that '*many conventional economists and financial analysts are unaware of the fact that the national economy is based on a national hydrology*'.

9.2.1 Sub-Saharan Africa's Achilles' Heel

Similarly, the South African scholar Schulze (2001, 2007) has stressed the "*strong need for an 'Africanized' model, for use at appropriate smaller scales, physical-conceptual in structure, so that it is sensitive to local land use/management conditions, and addresses the rural issues to which Africa needs answers*". He has pinpointed a number of phenomena that sets Africa much apart from temperate climates of many developed countries:

- very high potential evaporation;
- very high aridity;
- low runoff generation;
- very concentrated rainfall seasonality;
- strong response to the El Ninõ-Southern Oscillation signals in terms of high inter-annual rainfall variability;
- many small rivers that tend to be ephemeral.

Criticising the dominance of Eurocentric hydrological models, developed for data-rich temperate climate situations, he raised the crucial question '*Are we asking the right questions?*'

His colleague Odbiambo (2001) has called for a '*paradigm shift that moves well beyond the purely technocratic and economic approaches, which particularly identify the skills necessary for immediate solutions to freshwater management*', and asked for '*the longer term and much broader governance of freshwater resources. which constitutes, in fact, humankind's ultimate goal*'. He remarked that one cardinal pillar in the new African doctrine of governance of freshwater resources is '*that the operating quantum must be the entire watershed, and its functional subsets, such as city conurbations*'.

9.2.2 Sub-Saharan Africa's Hydroclimatic Reality

Taking, in line with Schulze (2001), a physical-conceptual approach to the SSA, the hydroclimate can be seen as the product of the interaction among rainfall, potential evaporation and resulting runoff generation (Fig. 9.3). What primarily distinguishes the regions (central basin) from the northern temperate region (left basin) is the very large 'thirst of the atmosphere', i.e. the extreme potential evaporation. The higher

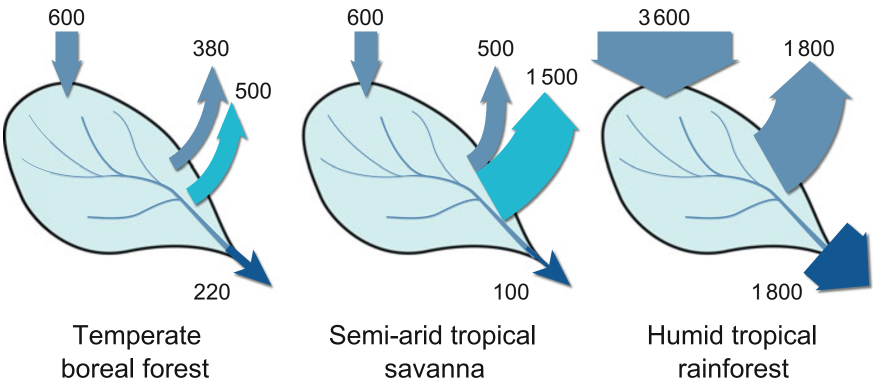


Fig. 9.3 Water balance differences between three main hydroclimatic regions, presented through typical basins (top arrow, precipitation; dark right arrow, actual evaporation; light right arrow, potential evaporation (thirst of the atmosphere); lower arrow, runoff). The semi-arid tropical savanna is distinguished by the extreme potential evaporation (based on Falkenmark and Rockström 2004)

this vertical water flow, the lower will be the rainwater surplus turning into horizontal runoff. Where the runoff generation is low, it may even evaporate before reaching the river, resulting in river stretches carrying water only during rainy periods.

Similar to Schulze, Weiskel et al. (2014), has maintained that up till now, the globally dominating water resources development approach has been characterised by a *blue-water bias* by mainly focusing on the particular situation in the humid, mountain-source regions, serving just 20% of the world population. Such an approach is poorly fitted to the situations in the dry climate half of the world's land area, where most of the rain evaporates, resulting in limited runoff generation—as demonstrated by the central basin in Fig. 9.3. This is, in fact, the region where poverty and hunger continues to dominate—problems that the SDGs, declared by the UN in 2015, aim at alleviating (Falkenmark and Rockström 2015; UN 2015). Two basic conditions for moving towards poverty mitigation and hunger alleviation are adequate urban raw water supply, and safe water for local food security.

For understanding the specific Sub-Saharan water availability dilemma, a clear idea of water's existence in the landscape will be essential. The water balance distinctions illustrated in Fig. 9.4 focus on different combinations of, respectively, horizontal and vertical water inflows to and outflows from a landscape unit. In *humid regions*, flow-through regimes are dominated by *blue water* inflows and outflows, whereas in *drylands*, with low runoff generation, vertical water flows or *green water* flows (rainfall and evapotranspiration), are dominating the water resource situation. There, since blue water withdrawals and return flows would tend to deplete or churn the natural systems, development will depend on green water practices to protect or restore soil moisture (the green water reservoir) and to carefully manage green fluxes, i.e. precipitation and evapotranspiration.

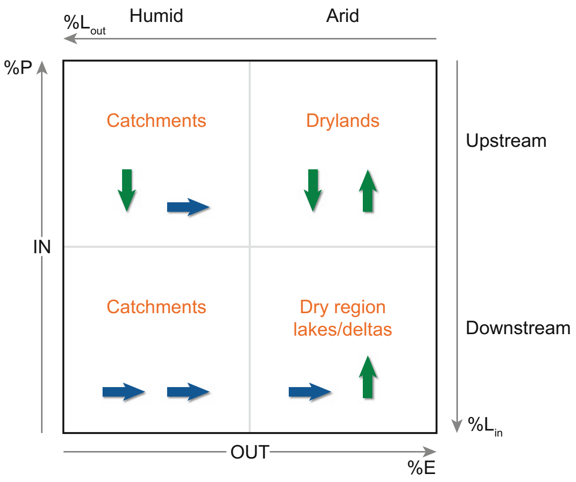


Fig. 9.4 Categorisation of different hydroclimatic landscape situations, based on composition of water inflow and outflow. according to Weiskel et al. (2014). Axes show percent vertical water. P, precipitation; E, evaporation; L_{in}, river inflow; L_{out}, river outflow. In *humid regions*, flow-through regimes are dominated by blue water inflows and outflows, whereas in *drylands*, with low runoff generation, vertical water flows or green water flows (rainfall and evapotranspiration), are dominating the water resource situation

In 2005, Vörösmarty et al. (2005) presented an essential contribution to our current understanding of Africa's hydroclimatic reality, with blue water largely concentrated in river corridors. This understanding will have significant development implications for SSA where its dry climate, exacerbated by climate change and increasing rain variability, is expected to result in even more frequent and severe drought years.

Furthermore, Africa's rapid population growth makes attention to population-driven water shortage, i.e. water crowding, essential. As showed later, when the population, already before the end of this century, is expected to have increased four-fold, all the savanna zone countries can be foreseen to be suffering from chronic water shortage. The Sub-Saharan hydroclimatic reality therefore demands an urgent shift in thinking towards incorporating adequate attention to green water/infiltrated rain—fundamental for finding the way to a sustainable future for the continent.

9.3 Blue Water Realities and Water Supply Challenges

Ultimate base for the Sub-Saharan socio-economic development is the precipitation, systematically increasing from the deserts to the humid tropics. Precipitation tends to be higher over local mountains, which function as water towers and source areas feeding water flow into river corridors. As a consequence, the locally available blue water will have to be shared between primarily societal water supply of cities and industry, while food production to feed a rapidly growing population will primarily have to remain rainfed, and based on soil moisture from infiltrated rainfall, i.e. green water. Many countries suffer from endemic water scarcity, increasingly constraining their socio-economic development—particularly in eastern and southern Africa.

9.3.1 Water Towers and River Corridors

Blue water appears in basically two forms: as *river corridors*, basically originating from isolated water towers in the landscape (Fig. 9.5a), and as locally generated runoff over the savanna, where it might in the future be locally harvested before it evaporates. The map shows that the drainage pattern—except for passing large rivers—is quite sparse in arid and semiarid zones, including Mali, Niger, Chad, Sudan, Zimbabwe, Botswana and Namibia. Large African rivers are transnational requiring international water management agreements for use as raw water sources (Turton 2012).

The groundwater situation is shown in Figs. 9.5b, c. Basically, there is plenty of groundwater stored under the African soil but in the drylands, the depth to the water table is generally more than 25 m, deepening towards the Sahara (MacDonald et al. 2012). Aquifer productivity is generally low (below 1 l/s), except in central Sahel and in Angola. Only northern Africa has large sedimentary aquifers, most of which are however no longer recharged.

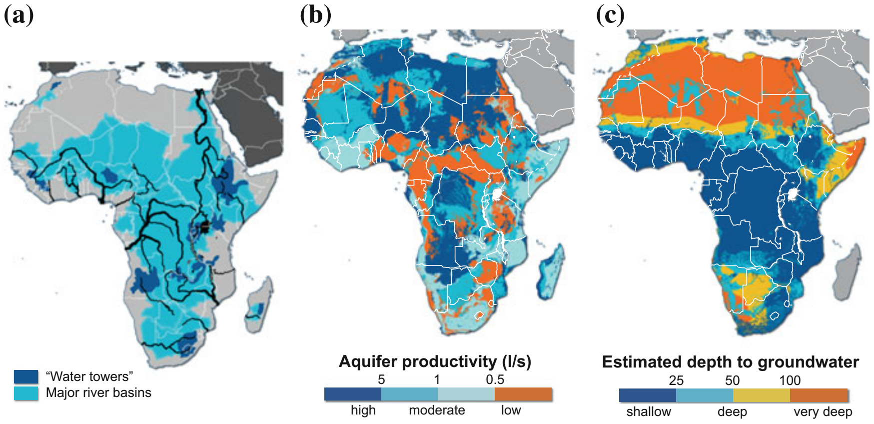


Fig. 9.5 Blue water availability: **a** water towers, major rivers with main tributaries and selected drainage basins (based on UNEP 2010), **b** aquifer productivity is generally low in SSA, with the exception of central Sahel and Angola (based on MacDonald et al. 2012), **c** groundwater is shallow in dryland regions, deepening towards Sahara, eastern and south eastern Africa (based on MacDonald et al. 2012)

9.3.2 City Water Supply Challenges

Currently, some 50% of the African population is urban, and urbanisation increases continuously. The African urban population is expected to grow faster than in any other world region and absorb practically all the population growth (Varis 2006). By the end of the twenty-first century, 70% of the population is expected to be urban. According to UN DESA (2014), Africa had, by 2014, 39 large cities (more than 1 million inhabitants), by 2025, projected to amount to 80 cities.

A current Stockholm International Water Institute (SIWI) study has looked at the urban raw water problem (Falkenmark and Tropp 2016), revealing that, in coming decades, the water supply challenges will be massive, and the 'booming city future' in Africa will demand the Herculean task of securing, in only 15 years, water supply for hundreds of millions of African city dwellers. Water supply infrastructure will have to be a core component of liveable cities (Ng 2018). The size of the task will be compounded by the size of the population growth and the related stress on the city's infrastructure with its services in terms of both food, water and electricity.

Figure 9.6 illustrates the massive task and the relatively short time available, for securing safe water supply for African cities, with urbanisation estimates from African Development Bank (2011). Since the overall blue water availability now amounts to 4000 km^3/year, it may, by 2100, be down to only 1000 m^3/capita/year (4000 billion m^3/year divided with 4 billion people) i.e. will have reached so-called chronic water shortage on a sub-continental level. Assuming 200 m^3/capita/year for gross urban water supply (Falkenmark and Xia 2012), combining human, industrial

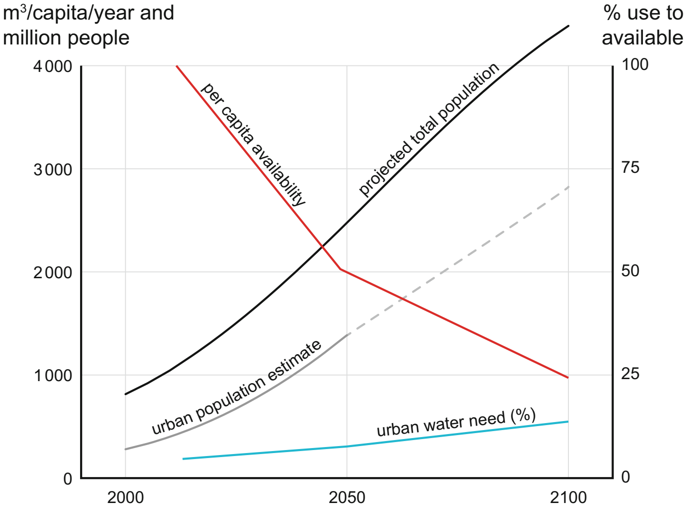


Fig. 9.6 Foreseen regional water scarcity development in Africa 2010–2100. Presented on the left scale is *per capita* availability (m^3/capita/year) and total and urban population (millions, UN DESA 2014, 2015). The right scale shows estimated relative urban water demand (% of availability)

and energy water supply, the city water requirement will, by 2100, have grown to 560 km^3/year for gross urban water supply (2.8 billion people multiplied by 200 m^3/capita/year), i.e. some 14% of the overall blue water availability.

When considering the urban population growth, and the risk for social unrest if allowing uncontrolled growth to alienate citizens, city authorities will evidently have an instrumental role to play in balancing the housing and infrastructure needs against pace of growth.

9.3.3 Three Contrasting Raw Water Situations

According to the SIWI study, the urban water supply systems will have to be built up under an era of rapid increases in water demand and increasing efforts to link the city to outer world economy. In view of the variability in geographic/hydrological and financial constraints, many different types of raw water sources will have to be contemplated. Table 9.1 exposes one possible way of predicament distinctions, based on the type of water appearances in the landscape: closeness to river corridor, savanna land with low blue water generation, accessible groundwater aquifer, exposure to large-scale flooding, etc.

Even though smaller and mid-sized cities are those growing relatively faster compared to larger ones, the larger cities will be important economic engines. For example, Nairobi is not only a critical national economic hub, but increased and secure water supply to Nairobi will be a cornerstone of the Kenya government's Vision 2030 to develop the region into a world-class commercial centre (Varis 2006). The city is expected to grow from 3.2 million inhabitants to 5.5 million in 2030, and the increasing urban populations and expanding economic activities will evidently involve rapidly mounting water pressures (both municipal, industrial and energy production).

Table 9.1 Hydrological raw water source predicament categories with city illustrations, based on landscape characteristics

	Lean source	Rich source
River	A: Small river/seasonal source *Nairobi, Johannesburg, Addis Ababa*	B: Large river/perennial source *Niamey (Niger)*
Savanna	C: Arid/semi-arid landscape dependent on rainwater harvesting/pumped groundwater *Lusaka, Gaborone*	

9.4 Water for Food Production—A Massive Green Water Challenge

We now turn our focus to water for feeding the African population, in line with the Malabo declaration (African Union 2014) and the UN's SDG goal 2 to eradicate hunger by 2030 (UN 2015). Except for the wet equatorial areas, the Sub-Saharan landscape is dominated by subsistence agriculture on savanna land, Fig. 9.7a, characterised by low rainfall increasing from the desert towards the rainforests.

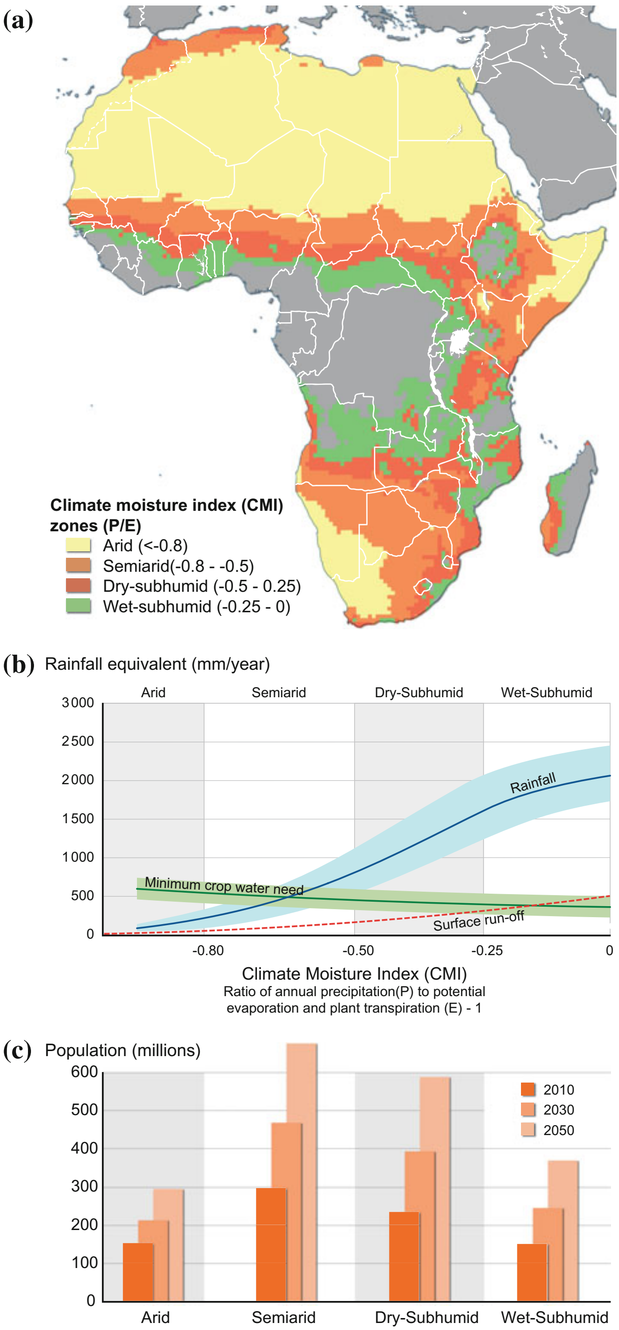
9.4.1 Hydroclimatic Dilemma

Low and unreliable rainfall in the arid and semi-arid zones makes agricultural vulnerability large, presented as the crossing curves in Fig. 9.7b, where the highly variable annual rainfall is related to the crop water requirement (Falkenmark and Rockström 2015). In some years there may be sufficient rain to allow a crop to mature, while in other years, conditions will be too dry to allow a crop to mature. The current situation is mirrored in widespread poverty and hunger in the semi-arid zones, with the highly fluctuating rainfall between good years and bad years. The vertical columns in Fig. 9.7b show population size in the different climatic zones by, respectively, 2010, 2030, and 2050. It visualises the rapidly growing population to be fed, and the vulnerable livelihood situation, that the SDG targets are expected to overcome without much delay.

9.4.2 African Subsistence Agriculture

In view of the particular blue water geography in SSA, it is not surprising that agriculture remains mainly rainfed. Most subsistence farmers live far away from the large river corridors (Vörösmarty et al. 2005) with limited possibilities for conventional irrigation, and hunger and poverty are widespread. The hydroclimatic regime makes rainfed agriculture problematic and unreliable, and involves exposure to frequent droughts and dry spells (Mertz et al. 2012). In regions with easily degradable soils, intensive rains easily form flash floods and erosion, and crops are easily degraded by drought damage, limiting their water uptake capacity of the roots. Agricultural productivity is therefore low with crop yields around only 1 ton/ha.

Since poor soils make water losses large, water use efficiency and crop yields remain low, but opportunities exist for a certain yield gap closure: on the one hand, large blue water losses both as surface water and as surplus percolation down to the groundwater, and on the other hand, large evaporation losses due to poor root water


(a)
Climate moisture index (CMI) zones (P/E)
Arid (<-0.8)
Semiarid(-0.8 - -0.5)
Dry-subhumid (-0.5 - 0.25)
Wet-subhumid (-0.25 - 0)
(b)
Rainfall equivalent (mm/year)
Arid
Semiarid
Dry-Subhumid
Wet-Subhumid
3000
2500
2000
1500
1000
500
0
Rainfall
Minimum crop water need
Surface run-off
-0.80
-0.50
-0.25
0
Climate Moisture Index (CMI)
Ratio of annual precipitation(P) to potential evaporation and plant transpiration (E) - 1
(c)
Population (millions)
600
500
400
300
200
100
0
2010
2030
2050
Arid
Semiarid
Dry-Subhumid
Wet-Subhumid

◂**Fig. 9.7** **a** Africa's semi-concentric savanna landscapes (data from Vörösmarty et al. 2005). **b** Hydroclimatic zone profile from arid, to the left, to wet sub-humid, to the right. The rainfall curve shows rainfall plus/minus one standard deviation (blue). Crop water requirement curve shows requirements plus/minus one standard deviation (green). **c** Population per hydroclimatic zone, 2010 estimate and projections (based on Falkenmark and Rockström 2015)

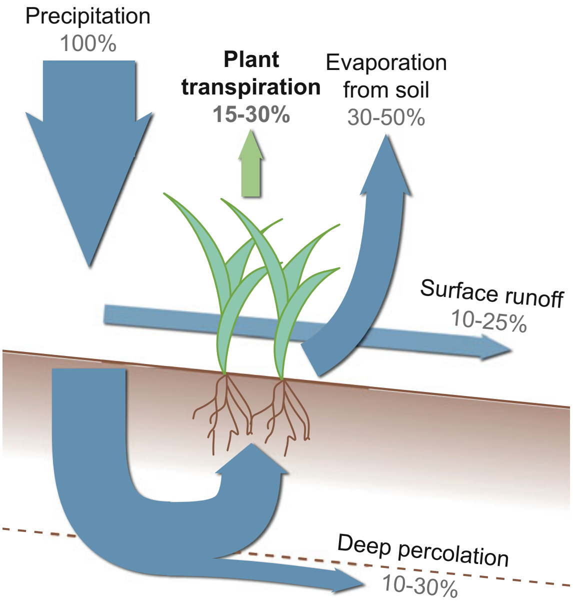


Fig. 9.8 Typical water flows on a subsistence farmer's field in the savanna zone. Losses via run-off, evaporation and drainage are so large that only 15–30% of the rain becomes available for plant growth (transpiration) (based on Rockström et al. 2014)

uptake. Full use of the available rainfall would however allow many times higher yield (Rockström and Falkenmark 2000).

The huge water losses (Fig. 9.8) might, however, be *treated as a resource* and made productive by an integrated approach to soil and water management: soil tillage for improved rainfall infiltration, reducing surface water runoff, and water harvesting to allow supplementary irrigation for protecting crop roots from dry spell damage (Rockström 2003; Falkenmark and Rockström 2004). Supplementary irrigation could be secured based on both rainwater and local runoff harvesting in local ponds (Critchley et al. 2008; Dile et al. 2013; Garg et al. 2012; Joshi et al. 2008).

9.4.3 Towards an African Green Revolution

Since the 1990s, making better use of green water by soil conservation and rainwater harvesting has been intensifying within agricultural sciences. Methods for selecting suitable rainwater harvesting sites in arid and semi-arid regions have been developed (Ammar et al. 2016)—Dile et al. (2013) showed that it was possible in an Ethiopian basin to increase staple crop production by up to threefold after better nutrient application. A green water revolution perspective has, in the past 10 years, begun to enter official documents, as shown by the following examples:

- 2006: Alliance for Green Revolution in Africa (AGRA) committed to launching an African Green Revolution (Bill and Melinda Gates Foundation 2006);
- 2010: building on the 1969–1990 Green Revolution promote a Greener Revolution in Africa, increase irrigation to increase food security; great potential for harvesting water runoff in lowlands and valley bottoms (UNEP 2010);
- 2011: need for biologically based green revolution (African Development Bank 2011);
- 2014: Malabo Declaration: accelerate agricultural growth by at least doubling current agricultural productivity levels by 2025; provision of ‘smart’ protection to smallholder agriculture; need for efficient and effective water management systems notably through irrigation (African Union 2014);
- 2015: need for climate smart agriculture; better use of green water; avoid reliance on abstraction of blue water (Williams et al. 2015);
- 2016: study on ‘Resilience of African Drylands’; irrigation probably not the solution for the vast majority of dryland households (World Bank 2016).

An integrated blue-green approach, tends to see the huge water losses in today’s subsistence farming in Africa as a resource, benefited from in a so-called t*riply green revolution* (green for, respectively, green water, productivity increase, and environmental protection). Combining soil and water management, a *triply green revolution* would give synergy effects, i.e. increasing productivity, making better use of the green water available, and allowing productive recycling of nutrients and organic matter through productive sanitation (Falkenmark and Rockström 2015). The untapped potential to save water in food production is largest in the lowest yielding savanna regions (Rockström 2003), and these are also the regions where growth in food requirements is fastest due to population growth and where a green revolution is therefore particularly needed.

The productivity of semi-arid Sub-Saharan lands has been addressed over more than 30 years in response to the UN Convention of Drought and Desertification (Falkenmark and Rockström 2008). There, land degradation has been taken as the focus, and much attention has gone into efforts to contain the desert by tree-planting along the desert border. Building on experiences of the Algerian Green Wall and a similar programme in China around the Gobi Desert, a new Sahelian tree-planting-oriented programme was launched in 2012, the Great Green Wall Initiative of the Sahara and the Sahel (AMCEN 2012).

At its First Conference, in May 2016, the World Bank presented a start of the art study on the 'Resilience of African Drylands' (Cervigny and Morris 2016), indicating the shared interest in wise management of green water for sustainable development of the semi-arid zone, indicating a need '*for integrated landscape management to restore degraded areas to functional and productive ecosystems ... so that food is more available and more affordable after shock hits*' (World Bank 2016). Similarly, in the SDG activities, land productivity improvement is highlighted both in SDG goal 15, aiming at reaching the Rio+20 goal of a 'land degradation neutral world', and in SDG goal 2, aiming at reaching hunger alleviation (UN 2015).

9.5 Water Scarcity Hotspots

While we, in Sect. 9.4, were clarifying the principal hydroclimatic implications for water-dependent societal sectors (city water supply, water for food production), we will now look for the hotspots by turning our focus to fundamental regional differences. A pixel-based modelling study by Schuol et al. (2008) offers the opportunity to coarsely identify regions particularly vulnerable to sharpening water shortage; both *blue water shortage*, influencing the development of urban, industrial and energy water supply, and *green water shortage*, limiting food production opportunities for expanding populations.

9.5.1 Regional Blue Water Scarcity

It should be recalled that, when analysing blue water scarcity, two aspects have to be distinguished (see Fig. 9.9):

- the difficulty of mobilising an even larger part of the availability, i.e. increase use-to-availability ratio or criticality (increasing the *water stress*);
- water as part of the physical environment in the sense of how many people that are competing for, and contributing pollution to, each flow unit (increasing shortage or *water crowding*).

Box. Water stress versus water crowding

When water shortage, in terms of water per person, is now sharpening in the dryland areas of Africa (cf. Fig. 9.6), it is essential to be aware of two contrasting perspectives, not well distinguished in the past. Figure 9.9 shows the difference between *water stress*, referring to the relative amount of the total water availability being already mobilised and put to use (vertical axis), on the one hand, and on the other *water crowding*, referring to number of people both sharing and contributing pollution to each flow unit of water (horizontal axis).

On the vertical axis, development will step by step be approaching a *peak water level*, beyond which increasing water needs will have to be met in other ways, like water use efficiency, demand management, wastewater reuse, desalinisation, decoupling, etc.

On the horizontal axis, population growth will lead to increased crowding, and can be expected to have social implications with increasing health problems, discontent, xenophobia, etc., and will have to be met by governance efforts well in advance, in order to avoid societal unrest and secure societal order.

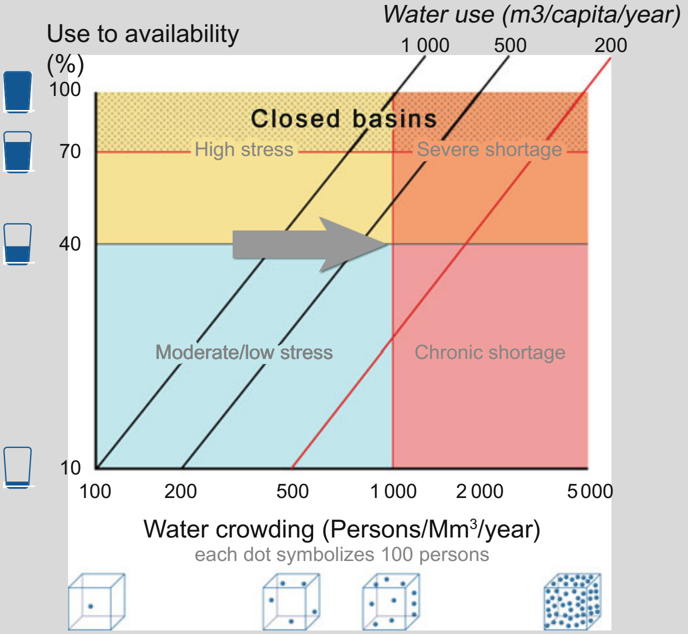


Fig. 9.9 Two modes of water scarcity (based on Falkenmark et al. 2014). The vertical axis presents the mobilisation rate ratio, making increasing amounts of water availability accessible for use (water stress). At the amount to be protected for aquatic ecosystem health (ecological flow, here 70%), the mobilisation level is maximised (peak water). The horizontal axis shows water crowding (people per flow unit of water of 1 million m^3/capita/year) indicating the number of individuals jointly dependent on, and polluting, each flow unit of water. The arrow indicates the effect of population growth. Beyond 1000 people/flow unit, water crowding is characterised as chronic water shortage

The potential per-capita water use in each point of this diagram is indicated by the diagonal lines, moving from high per capita uses possible at the low levels of water crowding, towards low per capita levels in the chronic water shortage regions towards the right in the diagram (Falkenmark et al. 2014).

9.5.1.1 Blue Water Crowding

A presentation of the situation in the last 30 years of the 1900s (based on the pixel level modelling by Schuol et al. (2008), is shown in Fig. 9.10a. Some semi-arid regions are already water stressed. Assuming an additional population of more than one billion, some preliminary conclusions can be drawn on the future situation.

The expected freshwater shortage situation in Africa by 2050 on the national level is shown in Fig. 9.10b, in terms of inverted water crowding (Turton 2012). By 2050, the chronic shortage region will be covering much of the major semi-arid region. Two regions are particularly exposed in SSA: respectively, eastern and southern Africa; the former hosting the water sources of the Nile river, with several

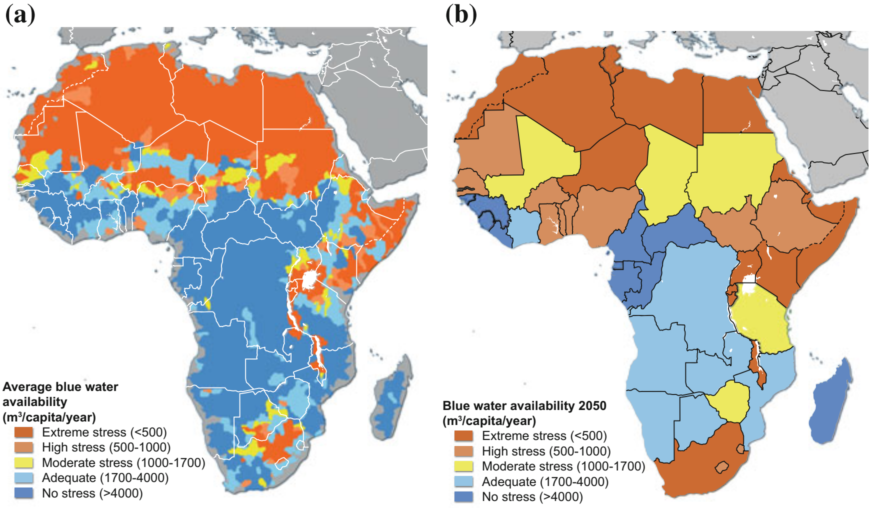


Fig. 9.10 Blue water shortage in Africa; **a** water availability *per capita* situation (i.e. inverted water crowding) in late 1900s with areas of chronic shortage (in figure referred to as "water stress") in the Sahel, eastern and northern Africa among other regions (based on Schuol et al. 2008); **b** country level projections for 2050 present major challenges in water availability for dryland regions (data from Schuol et al. 2008; UN DESA 2015)

large urban water hubs; the latter sitting on the sources of a quartet of transnational rivers, supplying a multitude of downstream countries with the water on which their socio-economic future largely depends (see Sect. 9.5.3).

9.5.1.2 Peak Water Approaching

Principally, below some 500 m^3/capita/year, i.e. beyond some 2000 people/flow unit, chronic water shortage can be foreseen to be constraining water dependent activities such as industry, energy and economic development. The economy is approaching the *peak water* level, involving transition from water supply being *demand-driven* to being *constraint-driven.* By mid-century, this situation can be foreseen to be dominating most of the Sahel and large parts of eastern and southern Africa. Already now, in the water mobilisation sense, southern Africa finds itself in an economically vulnerable state by '*water resources becoming a constraint to job creation and future economic growth*' (Turton 2012). Unless extremely wisely governing its water management, society may be risking '*a slow erosion of social cohesion as the unemployed become discontent, further exacerbated by the gradual loss of food security*'. This southern African dilemma is being further exacerbated by water quality consequences, such as the aftermath of the ceased large-scale gold mining in the capital area, in terms of a rising badly polluted groundwater, both acidic and radioactive—spilling into a transnational tributary, heading towards downstream Mozambique.

9.5.2 Regional Green Water Shortages, Short Growing Season, Large Drought Vulnerability

Since SSA's food production is mainly rainfed, the green water situation is of crucial importance for judging future food security potential.

While the blue water availability is highly vulnerable to population growth, the green water availability in terms of length of growing season (Fig. 9.11a) and drought vulnerability (Fig. 9.11b) is vulnerable to climate change (Mertz et al. 2012). The maps illustrate large regional, climatically driven green water differences. They show that the savanna zone (see Fig. 9.1) is dominated by semi-arid and dry sub-humid zones (Fig. 9.7) and their growing seasons (Fig. 9.11a) very vulnerable to droughts, reducing the growing season. Figure 9.11b suggests that a variability of about 1 month is quite widespread.

The maps thus indicate that broad regions in eastern Africa and southern Africa are particularly vulnerable to drought-related crop failures, requiring protective

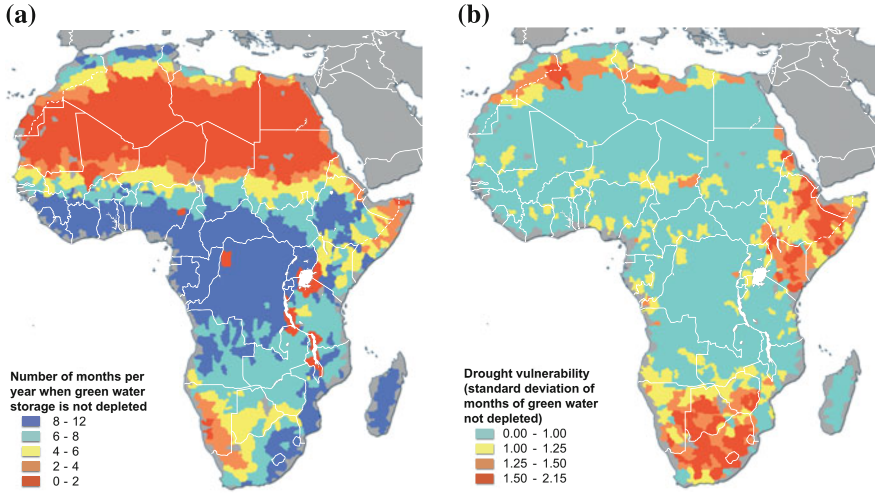


Fig. 9.11 Green water related characteristics in Africa (based on Schuol et al. 2008), **a** length of growing season (number of months when green water storage is not depleted), **b** drought vulnerability presented as the standard deviation of number of months when green water is not depleted, high standard deviation means more unreliable green water situation

irrigation from harvested rainwater and runoff from heavy rain in lowlands and valley bottoms to increase agricultural reliability (UNEP 2010).

9.5.3 Combined Water Scarcity Consequences

The highly water-shortage stressed situations in eastern and southern Africa with their increasingly water crowded societies makes an outlook to future water resources arrangements essential. Basically, precipitation provides the base for national economy and is thereby to be partitioned among:

- biomass production (green water);
- societal water requirements for development and security (blue water);
- downstream flow for co-riparian countries, crucially dependent on water from the same draining basin (blue water).

9.5.3.1 Hard or Soft Landing, Hydropolitical Risk

A fundamental conclusion when comparing Figs. 9.10 and 9.11 is the great vulnerability of eastern and southern Africa in terms of the combination of blue water shortage and drought vulnerability. The combined green-blue predicament of southern Africa is particularly interesting to look closer into, recalling its topographical functions as water tower for four transnational rivers of fundamental importance for the future of the whole southern region: Orange, Maputo, Incomati, Limpopo (Turton 2005). Population growth is pushing all these rivers towards water shortage related tipping points. While south Africa is hosting the water sources for these rivers, some of these basins are already in a state of river closure, and the basins all contain critically water-dependent downstream states. Southern Africa suffers from high drought vulnerability of its crop production which means that it would itself have clear interest in blue-water based irrigation development.

Conventionally, the river flow is seen as the blue water resource available for withdrawal up to a point where the remaining flow is required to secure aquatic ecological services (in dry climate of the order of 70% on the use-to-availability level). At this point of water withdrawal, the basin is considered *closed for further withdrawal* (Falkenmark and Molden 2008). There is, today, a tremendous concern that, over the last 50 years, many river basins in the world supporting important economies—indeed, many of the world's breadbaskets—have reached the closed limit, implying an increasingly water supply-constrained economy, requiring efforts such as increased water use efficiency, waste water reuse, desalination, green water use, decoupling solutions, etc. In that situation, a pertinent question is whether there will be a *hard or soft landing*:

- *hard* if the resource base fails to meet basic societal water requirements, causing hardship;
- *soft* if society is able to adapt to achieving a soft landing.

The potential amount of water supply that can be made available per capita and year at the level of basin closure is the inverted value of the water crowding (population per flow unit of one million cubic meter of water per year, cf. Fig. 9.9). Thus, the per-capita water availability at 1500 people/flow unit amounts to max. 500 m^3/p year; at some 3000 people/flow unit to only some 200 m^3/p year, a situation where most water is needed just for humans, industry and energy, but none for large scale irrigation (see below).

9.5.3.2 Constraint-Driven Urban Water Allocation

When water crowding increases, urban water supply difficulties will also increase, and early water supply preparedness get increasingly essential for social security. With the extremely rapid growth foreseen of the urban populations, rising from currently of the order of 0.5 billion, to more than five times as much by 2100, this will, in fact, be a core key to a sustainable future of Africa, involving a *supply-constraint driven urban water supply*.

Northwest China offers an interesting comparison in terms of such urban water allocation (water for urban/industry, secured environmental flow, water for irrigation) (Falkenmark and Xia 2012). Figure 9.12 shows one example of reasonable

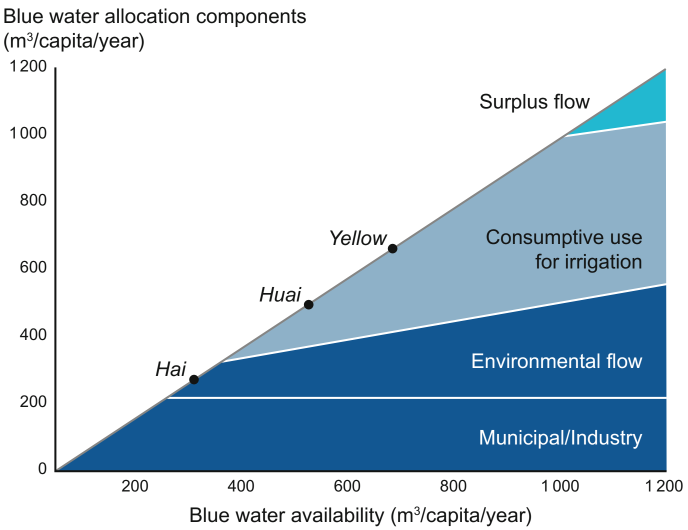


Fig. 9.12 Blue water allocation constraints in water short regions, example from northeastern China (Falkenmark and Xia 2012). The figure illustrates one possible supply-constraint driven allocation model, assuming municipal/industrial supply of 200 m^3/capita/year and giving second highest priority to ecological flow protection, and the implications for the Three H-rivers (Hai, Yellow, Huai rivers).

allocation for the highly water crowded three large rivers in north eastern China (Huai, Yellow and Hai rivers). It demonstrates one possibility of supply-constraint driven water allocation (gross city supply 200 m^3/capita/year, second highest priority to ecological flow protection). An alternative would be to reduce the urban and industrial water supply level to gain water for irrigation—this has been the solution actually preferred in northeastern China, limiting the city water demand to 90 m^3/capita/year.

9.5.4 Triply Green Revolution, Food Production Outlook

When related to the agroclimatic constraints, the very rapid population growth projected for SSA raises the issue of how far the region can, for hydroclimatic reasons, be able to feed their future populations. Many analyses tend to stress the importance of expanding irrigation (African Development Bank 2011) and hope for 25% increase by 2025 (Economic Commission for Africa 2006). One fact that tends to be neglected is that, in the savanna region, blue water availability is basically concentrated in the—often international—river corridors (Vörösmarty et al. 2005), while the majority of poor savanna farmers tend to reside far away from these blue water corridors.

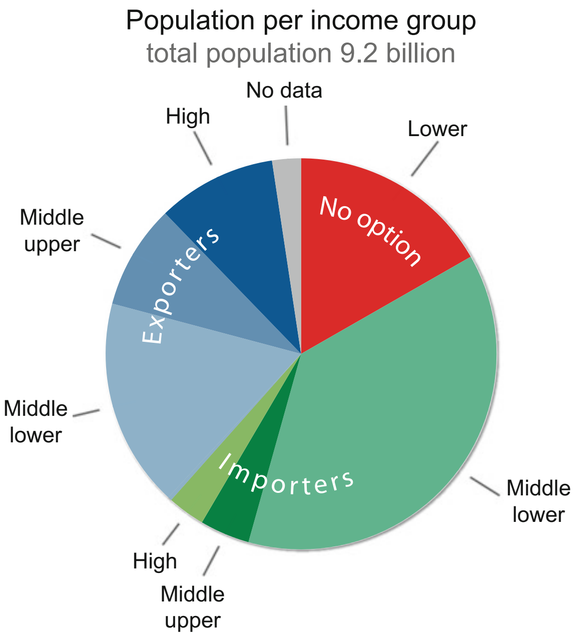


Fig. 9.13 Global overview of country estimates of water surplus (food exporters) and deficits (food importers) by 2050, grouped according to economic situation for a nutrition scenario with 3000 kcal/day/5% animal protein, assuming 25% yield gap closure (Rockström et al. 2014). Climate change and acceptable irrigation potentials are included. The comparison suggests that food water requirements will be too large to be possible to meet in a large number of countries. Groups to the left show populations living in countries expected to be able to export surplus, while sectors to the bottom and right show those dependent on food import for food self-reliance; the *no option* sector constitutes those possibly too poor for ability to carry the cost of food import

Assuming ability in terms of yield gap closure by productivity increase, Rockström et al. (2014) has thrown light on future food security in water short countries with rapid population growth. Figure 9.13 shows that extremely water short countries without possibility to increase food production will be critically dependent on ability to compensate their food deficiency by import, for which they —as already stressed—will be needing access to the foreign currency. This means that they will depend on developing a land-water integration based national planning to secure the industrial water required for that purpose. The blue countries would be able to produce food surplus; the green would depend on a certain level of food import.

Many countries in the importers and *no option* sectors are located in SSA and may be expected to suffer by 2050 from water scarcity constraining their food security. Several water rich countries in equatorial Africa (exporters) can provide surplus through inter-African food trade—‘*Africa can feed Africa*’ as formulated by the World Bank (2012). By 2050, many Sub-Saharan countries may remain too poor for import-based food security (no option group) and therefore depend on other non-conventional solutions, such as technical assistance, adapted diets, etc. An overview over nine such countries identified on what dietary level they would remain 'food self-sufficient' (Falkenmark and Lannerstad 2010), showing that on 2500 kcal/day/10% animal protein level, Ethiopia and Zaire would be able to be food self-sufficient; on only 2000 kcal/day/10%, also Burkina Faso, Eritrea, Gambia and Uganda might be just able to balance their diet. Most vulnerable would be Benin, Togo and Burundi, foreseen not to be able to feed their population even on a diet as low as 2000 kcal/day, vegetables only.

9.6 Discussion and Conclusions

Summarising, while the African population density still remains fairly moderate, many poor and medium income countries have high fertility rates, and more than 20 countries are already approaching chronic water shortage situations in the next few decades. Currently eastern Africa is advancing towards water-shortage related tipping points, while south Africa has already reached severe water shortage (Turton 2012), particularly serious in view of the implications for transnational rivers, fed by south Africa's water towers. Large regions can be said to suffer under a rapidly growing hydropolitical risk, composed of collision between dry climate, extreme population growth, and growing water needs. Since both water supply, food production and energy production all critically depend on access to water—blue as well as green—their sectoral interdependence will make a nexus approach among the three sectors essential.

9.6.1 Africa's Demographic Transition

The future of SSA is closely linked to its demographic changes (Canning et al. 2015; Varis 2006). The dry climate with low runoff generation, which makes food production mainly rainfed, matches poorly with the dominating blue water paradigm that tends to overemphasise blue (liquid) water, even in reports on Africa's future. This means that the earlier mentioned broad water blindness among societal economic planners will have to be addressed, securing proper water awareness in societal governance and infrastructure, to make possible development of skilful modes of water decoupling and successful leap-frogging in meeting rapidly expanding water demands whether green or blue. Particularly essential will be to identify adequate raw water sources for more than 80 big cities in the next 3–4 decades.

The activities needed to steer towards a safe Sub-Saharan future are no less than mindboggling: on the one hand efforts to reduce the time bomb, represented by the very high fertility rates, on the other successful adaptation to the rapid life expectancy-driven doubling of the grown-up population. The former is difficult to predict since they are aggregates of individual preferences. S*peeding up fertility decline* will have to involve a set of parallel types of activity: changing social norms regarding family planning, elementary knowledge of contraception, longer education of girls and later marrying ages, family planning programmes, easy access to affordable contraceptives, and social acceptability, etc., As fertility declines, reducing the number of children, the share of the working-age population will increase, improving the possibility to invest in its potential to contribute to economic growth.

Successful *adaptation to the increasing life expectancy* will demand development of decent livelihood condition*s,* realising that the current around 0.5 billion between 15 and 64 years of age can be expected to amount to more than 1.2 billion persons already by 2060 (another India as earlier pointed out).

9.6.2 Mastering the African Achilles' Heel

SSA's particular hydroclimate, with its extremely high evapotranspiration and limited runoff generation (only some 20% of the continent's rainfall), makes agricultural production unsecure, exposed to large water losses, low crop yields, and crop failures. The extremely rapidly growing population, complicates both the water management task and the water governance guiding it.

Not well adapted for addressing the continent's water challenges are conventional forms of blue water management (Williams et al. 2015), following examples from northern regions (Schulze 2007). In dryland regions such as those typical for the large savanna zone, attention needs to be paid to the water in the soil—the green water—brought by infiltration of rainfall. In view of currently large water losses in subsistence agriculture, a first step would involve productivity increase, based on conservation agriculture and protective irrigation, seeing non-productive evaporation losses as a water resource. This would include benefiting from two types of water harvesting: rainwater harvesting and/or harvesting of runoff from heavy rains. Today, the savanna surface runoff is increasingly thought of as a resource for supplementary irrigation (Ammar et al. 2016; UNEP 2010).

The exploding urban growth will have to be met by early planning of urban water supply—municipal, industrial and energy. Another issue to note is that in nearly all urban centres of Africa, water bodies within or near them tend to be heavily contaminated and are getting more and more contaminated with organic contaminants, chemicals and heavy metals. They are already encountering serious health and environmental costs, and are reducing the quantity of water available for future uses. African Development Bank (2011) has stressed that city growth remains largely unplanned, and that '*few African cities have municipal governments, capable of thinking through the complex set of coordinated decisions needed to deal with explosive urban growth*'. The interesting fact that so little attention seems to have been paid to accessibility of rich enough raw water sources is probably a remaining effect of a technical blue water bias, inherited from water-richer world regions. The extremely sparse interest in the literature paid to the fundamental life support issue of exploding cities is highly disturbing. Not even at the Habitat III meeting in the fall 2016 is the water supply challenges of booming big cities in Africa on the agenda.

9.6.3 An Africanised Model for Better Preparedness

African scientists have for at least two decades been stressing a set of phenomena, distinguishing Africa's hydroclimate from temperate climates of many developed countries. An essential tool for understanding the life support system's functioning in SSA will be a physio-conceptual mental model (Schulze 2001), sensitive to local land use/management conditions, including the current large-scale land-leasing originating from other water-short continents.

The Swiss model study by Schuol et al. (2008) might be useful for generating a preparedness without which today's optimism in many lion states may indeed be highly misleading. The water availability overview provided by that study shows that typical for the semi-arid land ribbon between the desert and the moist savanna land is the combination of high green water scarcity, critically dependent on rain water based supplementary irrigation, and a blue water crowding, that is rapidly, by the population growth, being pushed up into the chronic water shortage interval, when city water supply and water supporting the wanted industrial development is getting increasingly difficult to secure. It furthermore shows that two broad regions are particularly vulnerable from both a green and a blue water perspective: on the one hand eastern Africa, on the other southern Africa.

In future water management, it will also be essential to pay adequate attention to the very large water losses typical for today's urban as well as food water security management, and how they can be radically reduced.

9.6.4 Desertification: Historic Mistake not to Enter the Water that Exists

Quite remarkable has been the failure to see the water shortage perspective of land degradation management, misleadingly discussed as desertification abatement. A fundamental flaw that has most probably contributed has been the long-lasting focusing on soil dryness, i.e. *absence* of water, rather than the *presence* of water, i.e. the soil water that really exists (Falkenmark and Rockström 2008). The lack of awareness that improved land productivity in drylands fundamentally depends on the ability to meet deficient green water functions has been nothing but disastrous.

The World Bank Programme on 'Enhancing the Resilience of African Drylands', in particular, the report 'Confronting drought in Africa's drylands' (Cervigny and Morris 2016), presented at the First Conference of the Great Green Wall, in May 2016, is therefore a fundamental step taken towards approaching a sustainable development of SSA.

9.6.5 National Level Land-Water Integrative Planning

The combined dependence of SSA's life support system on both green water for agricultural production and blue water for cities, industry and energy production, calls for a water-food-energy nexus approach to avoid unexpected surprises. This combined dependence will demand a national level integrative land-water planning, where catchments are seen as the operating quantum, including their city conurbations, as fundamental subsets (Odbiambo 2001). Here, two aspects need attention: on the one hand, the upstream-downstream linkages between water activities, both upstream—green as well as blue—consumptive water use effects on blue availability downstream, and, on the other hand, damaging downstream effects on blue water usability of polluting activities upstream.

9.6.6 Atypical Economic Development—A Cause for Thought?

Not only municipal water supply and food production are critically dependent on access to adequate amounts of water, but also industry, where most industrial processes—including energy supply—involve water in many different functions. It would therefore not be surprising if the widespread Sub-Saharan water shortage would be reflected in industrialisation impediments. Signs of such a problem were, in fact, recently brought up in an article in 'Africa in focus': '*By any measure Africa's failure to industrialize is striking. In 2013 the average share of manufacturing in GDP in sub-Saharan Africa was about 10%, half of what would be expected from the region's level of development ... For an institution dedicated to 'ending extreme poverty and promoting shared prosperity', ignoring a sector that has the potential to create millions of well-paid jobs for people of moderate skills ... seems a major oversight*' (Page 2016).

9.6.7 Timescale Perspective

It is evident from Fig. 9.2 that SSA is exposed to extremely rapid change, driven not only by climate change, but by a fierce population growth in many poor and medium income countries: '*This isn't just a big deal because Africa will be almost as popular as Asia by 2100… It's a big deal because it's a reminder that growth this rapid changes everything*' (Fisher 2013). This can be foreseen to sharpen water shortage, particularly in eastern and southern Africa.

- ***Short term (2030)***. In a 13-year perspective, it will be found essential to address the destructively high fertility in many low income countries (Cervigny and Morris 2016, box 13.1), and to invest in cities with focus on planning, infrastructure and finance (African Development Bank 2011; UN-HABITAT 2014). Growing attention will be paid to issues such as increasing sharpness and frequency of droughts; how to manage socio-economic development under conditions of widening water shortages; a shift in thinking seeing food-water losses as a potential resource for increased food production; peaceful water sharing challenges in transnational river corridors; and—in view of registered increasingly severe health effects—the need to reduce water pollution in highly crowded river basins, especially in drought years.
- ***Medium term (2050)***. By mid-century, the growing life expectancy will have contributed to almost doubling the population. Food security will be requiring increasing food imports to cover growing food deficits, influencing the industrial development to generate enough foreign income for that purpose. Special attention will be drawn to food security problems in still-poor countries with remaining high undernutrition, to safeguard hunger alleviation, possibly at lower and better adapted dietary levels. Expanding chronic water shortage regions will require focus on increasing hydropolitical risk. Water governance and management will involve methods involving leap-frogging and decoupling to secure water for municipalities and industry.
- ***Long term (2100)***. It is essential to realise that population growth will continue in the middle-age layers of the population. It should not be expected that—due to the effect of life expectancy increase—the demographic transition can be finalised below some 3 billion inhabitants. This will demand increasingly sophisticated adaptation to the Sub-Saharan hydroclimatic realities. Only with highly water-wise governance could a foreseen 3–4 doubling of the population be successfully mastered. The alternative is massive outmigration to avoid very severe problems of social unrest and malcontent.

9.7 Final Remarks

We find ourselves at present in an era of awakening from decades of water blindness without much attention to the characteristics of Africa's arid climate and sharpening water crowding. Sharpening and more frequent drought problems are causing worldwide concern, strengthened by an already evident outflow of African migrants towards Europe. In the water society, worry is growing for the lack of attention to the life support system's fundamental dependence on water, and the risk for a hard landing, causing social hardship, unless rapidly addressed.

Extreme population growth in drylands involves growing hydropolitical risk, reflected in, not only national but also international security disturbances, threatening the intended advances towards the UN SDGs. Especially severe is the lack of understanding among broad societal leaderships of how to find water for both booming cities, with Africa growing to host some 80 large cities already by 2025 (UN DESA 2014) and development towards food security on an increasingly crowded dryland continent, were possible water resources for irrigation are either blocked in transnational river corridors, or flowing across savanna lands, where they tend to evaporate before reaching a river. Good news is that realism is now expanding on the dependence of the same water—the green water in the soil—of both trees and crops. and therefore, the need to coordinate the efforts in the Great Green Wall project with the efforts to intensify food production to make the population in the African drylands food secure.

Concern for Africa's vulnerability is growing also in the general media debate, for instance, in Washington Post recently, where Fisher (2013) stressed that '*right now, many African countries aren't particularly adept at either governance or resource management. If they don't improve, exploding population growth could only worsen resource competition—and we're talking here about basics like, food, water and electricity—which in turn makes political instability and conflict more likely. The fact that there will moreover be a 'youth bulge' of young people makes that instability and conflict more likely. It's a big, entirely foreseeable danger. Whether Africa is able to prepare for its coming population boom may well be one of the most important long-term challenges the world faces right now*'.

And there exists, in fact, encouraging experience in other water short regions of the world, where water shortage challenges have been possible to overcome. Of fundamental importance for success is, however, that politicians become rapidly aware of Africa's Achilles' heel, the great vulnerability that it involves, and the extreme urgency of adequate action, both as regards water supply of rapidly growing cities, and safe and rapid smallholder agricultural development. The latter was recently addressed by an expert *call for an African Walter Revolution* at the 2016 World Water Week in Stockholm.

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Chapter 10
Singapore: Transforming Water Scarcity into a Virtue

Peter Joo Hee Ng

Abstract Water has, is and will always be a national preoccupation for Singapore. Managing scarcity and safeguarding water security loom large in the minds of Singapore's leaders and the calculations of Singaporean administrators.

Keywords Singapore · Water scarcity · Catchment management
Desalination · Reuse

10.1 Water Scarcity

Of course, water scarcity is not unique to Singapore. The world seems to be careening towards water crisis. The warnings have been loud and dire for some time now: severe water shortage is the most likely danger that will imperil humanity in the near future. Population growth, unconstrained urbanisation, unpredictable weather and poor governance conspire to place overwhelming pressure on the world's water resources. The World Economic Forum (WEF) saw fit, in its previous two meetings, to elevate water crisis to the top of its annual list of leading global risks (WEF 2016, 2017). The World Bank, in a recent report, warned that only a paradigm shift in resource management will prevent water shortages from imposing a severe constraint on the economies of Middle Eastern, African and Central Asian countries in the next decade (World Bank 2016).

Even traditionally well-endowed regions find themselves short of water. In 2016, Ethiopia—the water tower of East Africa—had suffered its worst drought in half a century. As a result, food production had been decimated, plunging millions of Ethiopians into severe hunger. Venezuela was in a particularly bad state; its reservoirs were depleted. Dependent on hydroelectric generation, the oil-rich country was mired in both a water and power crisis. In Asia, dry weather in the Mekong Delta had devastated the rice crop, shrimp farming and coffee cultivation in southern Vietnam.

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Water rationing for a million consumers had been in place for months in the Malaysian state of Johor as reservoirs there fell to critically low levels. Right across the border in Singapore though, the notion that there may not be enough water has neither been remote nor novel. It has long been accepted that, despite sitting right on the equator and in the tropics, Singapore is, for all purposes, a water-stressed country. A large city and sovereign all at once, there is just not enough space in the city-state to collect and to keep all of the rain water that this thriving metropolis of 5.5 million requires to get by.

In reality, no large city is ever self-sufficient in water. Every conurbation is compelled to bring water from outside to quench the thirst of its citizens. The Romans built impressive aqueducts to feed their cities. New York City is famous for not having to filter its drinking water because city fathers bought and protected 5000 km^2 of pristine watershed in upstate New York. Hong Kong is dependent on mainland China for water, getting most of its supplies from the Pearl River. The city of Tokyo depends on a huge forest catchment well outside city limits for its water.

Despite this, modern Singapore is not short of water and it is confident that it will be self-sufficient in the long term. This makes the Singapore water story a unique one and worthy of closer study. Just how does Singapore do it?

10.2 Difficult Beginnings

Just 50 years ago, the water situation in newly independent Singapore was a constant source of worry. There was too much water and too little water at the same time.

With 30% of the island state less than 5 m above mean sea level and very poor drainage infrastructure, flooding was inevitable when heavy convectional and monsoonal rains coincided with high tides (Tan 2016). Close to 3200 ha of Singapore were deemed to be flood-prone in the 1970s (see Fig. 10.1).

Yet, at the same time, clean water was in short supply. The island's rivers were severely polluted because of unregulated discharge from the proliferation of squatters, farms, and cottage industries in their catchments.

The lack of surface storage further exacerbated the water situation. At independence in 1965, Singapore had to depend on three impounding reservoirs—MacRitchie, Peirce and Seletar—to capture whatever precipitation that fell on the island. Together, the trio just did not present sufficient capacity to tide the country over prolonged dry periods. This became painfully obviously to the people of Singapore in 1963, when water had to be strictly rationed for 10 months (Tan et al. 2008).

As Singapore's economy started to pick up speed, so did her population: from two million in the mid-1960s to three million by 1990, and then reaching five million by 2010 (see Fig. 10.2). This doubling of population in three decades was accompanied by a five-fold increase in water demand. Daily demand had been about 80 million gallons (mg) in 1965; it was around 220 mg/day in 1990, and is 430 mg/day today.

Fig. 10.1 Flood prone areas on mainland Singapore in 1970s compared to current. *Source* PUB Singapore

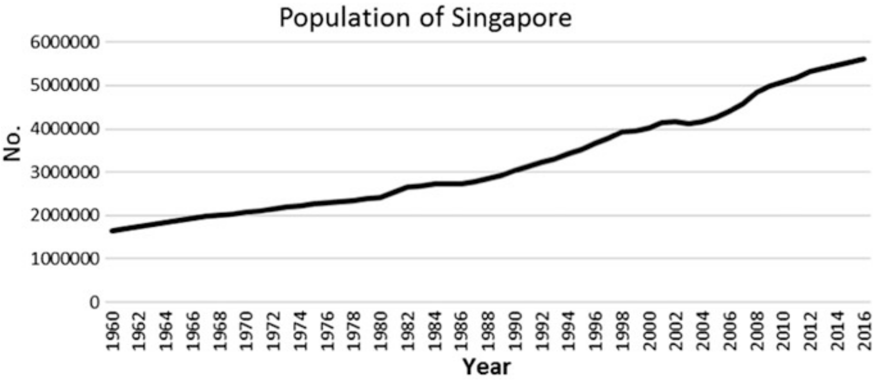

Fig. 10.2 Population of Singapore from 1960 to 2016. *Source* Department of Statistics

Along the way, competing land use added additional complexity to water supply planning. The constant need to expand the watershed had to be traded off against, and eventually reconciled with, demand for housing, commerce and industry. This balancing act continues until today (Tortajada et al. 2013).

10.3 An Existential Challenge

Behind the planning and action aimed at achieving long-term water adequacy is a siege mentality deliberately cultivated by Singapore's decision makers. Water security has always been positioned as nothing less than an existential challenge for Singapore. Its leaders have, since independence 50 years ago, declared that Singapore's continued existence as an independent nation is directly contingent on enduring water security. The late Lee Kuan Yew, Singapore's first prime minister, worked tirelessly throughout his life to secure Singapore's water future and had famously remarked that: '*Water dominated every other policy. Every other policy had to bend at the knees for water survival.*'

It is such clarity that explains Singapore's highly developed water strategy.

10.4 A Three-Part Strategy

Singapore's water strategy comes in three parts. First, it does everything it can to maximise its own yield, striving to collect every drop of rain that falls on the island and channelling the stormwater into storage reservoirs. This necessarily also means turning as much of its land area as possible, small as it is, into a watershed, and keeping its drains, canals and waterways pristinely clean.

Two-thirds of Singapore is now water catchment, making it one of very few places in the world to implement urban rainwater harvesting on the large scale (PUB 2016). Singapore's current 17 reservoirs now afford a satisfactory level of protection to her population from extended droughts. To eliminate contamination, sewer separation was conscientiously implemented from the beginning. In Singapore, stormwater drainage is entirely independent of the sewerage system (see Fig. 10.3).

Second, Singapore, perhaps more than anywhere else in the world, thinks of water as an endlessly reusable resource. In the minds of Singaporean water

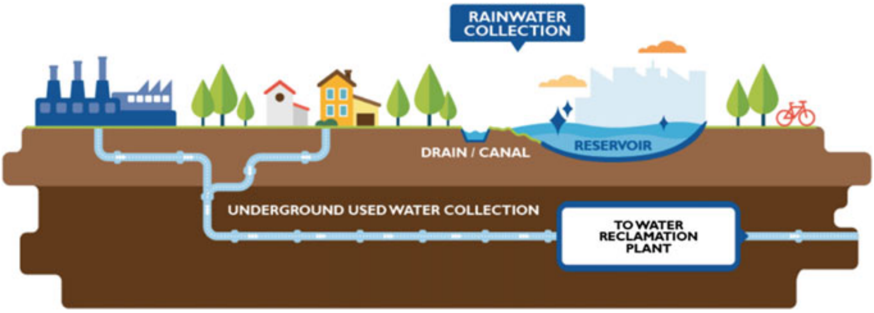

Fig. 10.3 Separate stormwater drainage system and sewerage system. *Source* PUB Singapore

planners, the H_2O molecule is never lost. We have long been convinced that water can always be reclaimed and retreated so that it can be drunk again. PUB, Singapore's national water agency, is a world leader in this. Today, PUB Singapore is able to literally turn wastewater into freshwater for very little money. Incredibly, Singapore collects every drop of her sewage and then reclaims it by turning much of it into drinking water again.

Third and no less important, the island nation has adopted desalination in a big way. When membrane separation technology made desalination economically viable, Singapore adopted it with great zeal. PUB Singapore currently operates some of the largest and most modern desalination plants in the world, and it continues to make large investments in desalination research to find technology that will allow it to de-salt for less.

Of course, such a strategy, even if perfectly executed, only guarantees the availability of water. The necessary corollary must be to use this water in the most efficient and productive manner. Every day, about 430 million gallons of water are consumed in Singapore. That is roughly 780 Olympic-size pools worth of water a day. Non-domestic use, by industry and commerce, accounts for 55% of total daily demand. And Singapore's demand for water can only be greater, as industry and commerce grow, and its population increases.

Singaporean domestic water consumption rate—148 litres/person/day—although already low by international standards, is still deemed to be wasteful. Singapore's populace is perennially challenged to be even more frugal and to use water ever more judiciously. Much of the water consumed by industry is used for cooling and processing. Because a lot of it is only used once, and then either lost to the atmosphere or discarded, this is considered to be unnecessarily profligate, and has to be continually curtailed through better engineering and the use of substitutes.

By addressing its water scarcity head-on and then diligently delivering on its water strategy, Singapore essentially makes its own luck. Its willingness to seek out alternative sources and to experiment has meant that it is exceedingly well positioned to exploit the potentially huge payoffs that accompany emerging megatrends.

This has been exactly the case with Singapore's early and wholesale adoption of wastewater reclamation and potable reuse, and with its enthusiastic embrace of seawater desalination.

10.5 Reuse Is a Megatrend

The Industrial Revolution gave humanity machines, factories and mass production, and greatly increased incomes and standard of living. It also created an economy that takes, makes and disposes, generating massive amounts of waste along the way. Now, we readily admit and acknowledge that taking the earth's resources to make the things we desire and then discarding them when they are no longer wanted is just not a sustainable way of living life. Indeed, when it comes to life-sustaining water, it is simply unacceptable that it should be tossed out after just one use.

From very early on, Singapore invested great effort and resource into researching technologies that would make wastewater potable again. When these proved feasible at the turn of new millennium, PUB Singapore adopted them with great zeal and promptly started to manufacture *NEWater*—which is ultra-high-quality recycled water—on an industrial scale. Today, it has sufficient *NEWater* capacity to supply about 40% of Singapore's daily demands.

Wastewater reuse is particularly attractive to Singapore because it is a drought-resistant source of potable water. That the requisite treatment technologies are now commonplace, and their reliability and efficacy well established and still improving, have turned potable reuse into a veritable megatrend. Even better, and unknown to most, making sewage potable actually requires, litre for litre, far less energy than desalination.

Of course, the challenge, even for Singapore, is to persuade people to imbibe after it has made the stuff. This remains a tricky issue the world over. Public acceptance of *NEWater* is high in Singapore, bolstered in part by the country's pre-existing water-stressed conditions. But Singapore continues to retain a careful and cautious approach. As such, even though *NEWater* is entirely potable, PUB Singapore has not yet rushed into direct potable use (DPU).

When it comes to DPU, public acceptance and good regulation are two sides of the same coin. One reinforces the other. Driven by necessity, DPU will come sooner rather than later. And it will become widely practiced, and a new norm, once enough reputable jurisdictions enact suitable regulation.

Every Singaporean grade schooler is taught the hydrologic cycle and knows how Mother Nature reclaims and recycles water in all its forms. What PUB Singapore does in its water reclamation plants and *NEWater* factories is, in essence, copying nature's way. Singapore has every motivation to do this. No doubt, the rest of the world will increasingly come to do the same.

10.6 Technology Can Only Get Better

At the time of writing, Singapore has enough desalination capacity installed to meet almost a quarter of its daily demand. The share of desalination within Singapore's water portfolio is significant in both scale and the speed that it has been achieved, given that its first desalination plant only came online as recently as 2005.

PUB Singapore is on schedule to bring another 15%-equivalent of daily demand in desalination capacity online by 2020. Indeed, ramping up desalination capacity from nothing to 40% of daily demand in less than 15 years is breath taking and probably unprecedented. Certainly, it is illustrative of Singapore's determination for source diversification and, more broadly, of the ever-improving viability for desalination to supply good water.

Singapore's decisive move towards desalination demonstrates a willingness to exchange water dependency for energy dependency. For a country poorly endowed with water and fully lacking in energy, this may at first seem surprising. But doing just so is astute and perfectly sensible. Water is a rarely traded commodity across national borders. A free and fully competitive global market, however, has long existed for energy supplies.

The real insight, though, for Singapore to be so aggressively bullish on desalination is the realisation that desalination can only get cheaper. Not because energy will become inexpensive, but the certainty that technology will progressively and inevitably lower the energy-take for de-salting seawater. Desalination may be weather-resistant but it is still a relative costly way of making seawater drinkable. State-of-the-art reverse osmosis desalination can currently deliver fresh water from the ocean for about 3.5 kWh/m^3.

Singapore, which imports all of its energy, possesses every incentive to reduce the power required for making seawater drinkable. And it is convinced that this can be at least halved in the near future. Working with collaborators, PUB Singapore is already showing, on a pilot scale, electro-deionisation to be a far more energy efficient way of taking salt out of seawater. The real promise, though, may well come from biomimicry and biomimetics, which are, unsurprisingly, the subjects of intense inquiry in Singapore's water research laboratories.

Ever improving science is only a megatrend when there is substantial and sustained investments in material, human talent and organisation. Singapore recognises that it will be high technology and clever innovation that would allow it to continue providing the life-giving water that it needs, and seeks three clear outcomes for water sector innovation: (1) increase water resources; (2) lower the cost of production; and (3) improve quality and security.

10.7 Conclusion

Because it cannot afford to be caught without sufficient water, or have sewage overflowing onto its streets, or floods devastating the country, Singapore takes an uncommonly long-term view when it comes to water management, planning decades ahead. Water planners at PUB Singapore know that Singapore's water system must be adequate, resilient and sustainable, all at once. Hence they decided, long before it was fashionable, that potable reuse and advanced seawater desalination would play starring roles in Singapore's water future.

Despite severely limiting geographic constraints, today's Singapore is not short of water. This is possible only because it has been coldly realistic about its circumstances; because it has used its intellect and imagination, researching and testing continuously; and because it continues to muster the political will to pursue and to implement hard-nosed policies.

Singapore believes that as long as it remains smart and clear-eyed about the country's water situation, and executes its plans relentlessly, there should always be enough water. In this remarkable way, Singapore has turned what was a disadvantage into strength, and what seemed an unsurmountable vulnerability into endless opportunity. And so this enlightened water husbandry makes everyday life possible, and a successful and prosperous Singapore a continuing reality.

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Chapter 11
Future Water Management: Myths in Indian Agriculture

M. Dinesh Kumar

Abstract Water management in India in the coming years will have to take an entirely different trajectory from what was followed since Independence, if recent trends are any indication. At the national level, the trends are: rising per capita incomes and improving living standards; rapid urbanisation and higher population growth rates in large cities; fast changing structure of the national economy; changing consumption pattern, with increasing preference for high calorie food—milk and milk products, and meat; fast improving transportation, and information and communication networks in rural areas; ageing population, and rising rural farm wages. These trends would create new water management needs and priorities for the future. Along with technological, institutional and policy interventions for water demand management, large water projects would be an integral part of the future solution. But, a section of the civil society argues that 'viable alternatives' to large water projects exist by propagating certain myths. This chapter makes an objective assessment of these 'alternatives' and shows how they fail to meet the future 'water management needs' by confronting these myths. Accordingly, the trends that are most likely to emerge in future in the water management sector are deciphered.

Keywords India · Agriculture · Water demand management · Water scarcity Soft paths · Civil society

11.1 Water and Agricultural Growth

In India since Independence, irrigation has been the key to enhancing grain production and ensuring food security at the national level, supporting nearly 60% of the country's population (Sharma 2011) in terms of food grains, pulses, fibre, oil seeds, vegetables and fruits. Though the contribution of agriculture to the national gross domestic product (GDP) has been declining fast since 1950–1951 (Fig. 11.1,

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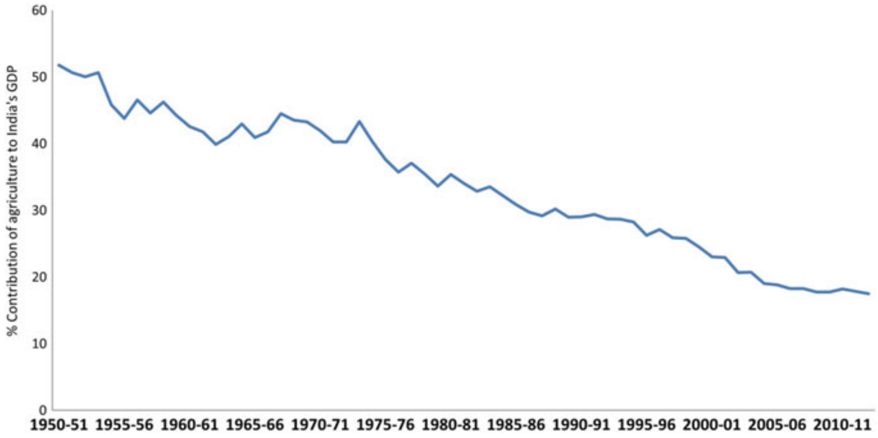

Fig. 11.1 Share of agriculture and allied sectors to India's GDP

based on GOI 2014) and now hovers around 17.6%, it still accounts for 49% of the employment in the country (KPMG 2016). But, this growth has not been uniform. A large chunk of the growth in agricultural production has come from the northern region, mainly Punjab, Haryana and Western Uttar Pradesh, which reaped the benefits of the Green Revolution rather rapidly (NRAA 2011).

The growth rate in TFP (Total Factor Productivity) is lowest for eastern region comprising Bihar, Odisha, Chhattisgarh, Jharkhand and West Bengal. Further, it has declined over three decades (1956–1987) from 1.5 during 1956–1965 to 0.70 during 1977–1987 (Evenson et al. 1999). During 1975–2005, the TFP growth in wheat has been lowest in Bihar and West Bengal, and that in paddy has been lowest in Bihar, Odisha and West Bengal (Chand et al. 2012). The grain yields are lowest in Bihar (Pathak et al. 2003). There are many reasons for the low agricultural productivity in this region. First is a low level of cultivation and use of irrigation. Irrigation, when compared with population size, is poorer in states such as Bihar and Odisha as compared to Punjab and Haryana, resulting in a very low per capita irrigated area (Kumar et al. 2012; NRAA 2011). The situation is Bihar is noteworthy due to it being one of the lowest per capita cropped areas (0.092 ha), and a high incidence of rural poverty. Nearly 32.6% of the people in the state live under poverty (Planning Commission, 2014) and the average per capita income of the state was a mere 40.6% of the national average (Biswas and Tortajada 2017). The constraints imposed by low per capita cropped area and irrigation are compounded by low yield levels (Kumar 2003).

Low levels of farm surplus, socio-economic deprivation, lack of public funds to invest in water resource development sector and poor availability of credit, which constrain technology adoption in agriculture, and poor political leadership act as three major challenges (based on Kumar et al. 2012; Kumar 2007; NRAA 2011).

In peninsular India, which has relatively high per capita agricultural GDP and TFP growth (Evenson et al. 1999), scarcity of irrigation water is becoming a major impediment to sustaining this growth. Inter-basin transfer of water from water abundant river basins to the water scarce ones could help augment the irrigation potential of these regions (Kumar and Singh 2005; Kumar et al. 2012), while augmenting the country's water supply potential by 200–250 Billion Cubic Metres (BCM). However, this must be followed by measures to improve the efficiency of water use in different sectors to achieve water demand management on a technological and institutional front. Particularly, greater attention should be paid to urban areas, with cities and towns claiming larger quanta of water (Kumar 2010, 2014a) and with non-revenue water (NRW) accounting for as high as 45% of the supplied water in certain cases (Kumar 2014a).

Demand for water in agriculture is growing due to increasing food grain needs of the growing population, and the growing preference for water-intensive cash crops. High pre- and post-harvest losses in food, which account for nearly 25% for cereals, oil seeds and pulses, nearly 40% for roots and tubers, and as high as 50% for fruits and vegetables (Gustavsson et al. 2011) are other factors that would increase the demand for water in agriculture in developing countries like India. In the urban and industrial sectors, the growth would be rather rapid, owing to the faster growth in urban population and rapid industrialisation. However, the scarcity is not going to hit all regions uniformly (Amarasinghe et al. 2008; Kumar 2010; Kumar et al. 2012). The naturally water-scarce regions, such as western India, south Indian peninsula (except Kerala), northwestern India and parts of central India, would be hit badly, as the demand for water from agriculture, industrial and urban sectors is high in these regions, while the renewable water resources available from within the region are low. This is compounded by the demand for water for reducing environmental water stress in the rivers. In the absence of proper legal regimes under which water can be allocated among the competing uses, water rights will be politically contested, leading to conflicts (Kumar 2010). Inefficient central and state water agencies and an absence of institutional arrangement for inter-state water allocation complicate further in most cases.

The large cities located in naturally water-scarce regions of India are heavily dependent on water imported from distant reservoirs (Mukherjee et al. 2010). The economically and politically powerful urban areas are likely to manage the huge additional supplies required from the rural areas with adverse implications for irrigated agriculture. Thus, agriculture in naturally water-scarce regions would be facing severe competition from other sectors such as industry, urban drinking and environment. The remarkable variations in the demand-supply balance across regions, and competing claims made by urban domestic, manufacturing and environmental sectors (Amarasinghe et al. 2004; Kumar et al. 2012) magnify the problem.

Approaches to water management in India in the coming years will have to take an entirely different trajectory from what was followed since Independence, including new water management models and innovative planning approaches, if recent trends are any indication (Biswas and Tortajada 2009). At the national level, the trends are: rising per capita incomes and improving living standards; rapid urbanisation and higher population growth rates in large cities; fast changing structure of the national economy; changing consumption pattern, with increasing preference for high protein diet—milk and milk products, and meat; changing composition of agricultural outputs, with greater contribution of horticulture, and dairy products; fast improving transportation, and information and communication networks in rural areas; and rising rural farm wages. These trends would create new needs and priorities in the water management sector for the future. As noted by Biswas and Tortajada (2009), ageing of the population, and retirement of the older generation with vast knowledge, experience and collective memory from the workforce, would pose new challenges.

However, a section of civil society has been demanding a new outlook on water management. The following views characterise this outlook: any water project that involve submergence of forests and human displacement should be completely avoided; rather than augmenting water supplies, water use efficiency in irrigated agriculture should be enhanced significantly to manage the demand for water in that sector and to allocate more water for other sectors; sufficient flows need to be maintained for environment in all rivers; the performance of new schemes should be assessed in relation to their ability to improve equity in access to water rather than augmenting water supplies; and new irrigation schemes, if at all required, should meet the growing needs of the farming enterprise, rather than contributing to the country's grain basket.

It is a well-articulated fact that large dams have a very important role to play in human development of developing countries, and there is really no other choice (Biswas and Tortajada 2001). Even in states such as Bihar, whose northern part is heavily prone to floods, trans-boundary water management in international rivers such as the Kosi, judicious water resources development for flood control and hydropower development can act as engines of economic development (Biswas and Tortajada 2017). While human displacement can be a major challenge to deal with, they can be made direct beneficiaries of the project for improving their lifestyles. In Brazil, upstream townships now receive 2% of the revenue from all electricity sales, in perpetuity. In Bhutan, each resettled family receives a certain amount of electricity free, in perpetuity. If they cannot use it all, they can trade that electricity at the market price. Such measures can significantly change the opposition to large water projects.

However, attempts were made by these interest groups to downplay the grave situation arising out of a scenario of not investing in large water infrastructure projects from the point of view of agricultural growth, rural development, food security and livelihoods. They propagated several myths to argue that viable alternatives to large water projects exist, or agriculture would not be a major claimant for water in future. These myths cripple healthy debate on water management solutions. In fact, the afore-mentioned 'outlook' on water management is part of a larger narrative to gain legitimacy for the 'alternatives'. In the process, what is ignored is that large dams are the best examples of rainwater harvesting, which they promote as 'alternative'. Therefore, large versus small is a wrong narrative for water debate in India. Rather, the discussion should focus on whether to go for 'large' or 'small'.

11.2 Where Would the Future Growth in Water Demand Come from?

Myth: When economy grows, more water would be used for domestic and manufacturing sector, and less for agriculture.

Reality: With growing population and rising income levels, India would require more food in the form of cereals, livestock products including milk, milk products and chicken, increasing the demand for water.

It is important to recognise the fact that the average calorie intake, which is one of the lowest in the developing World, is going to increase substantially in the coming years, with rising per capita income. Anyway, the demand for dairy products has been growing exponentially in India—from a low of 42 kg/capita/year in 1979–1981 to 71 kg/capita/year in 2005–2007 (Alexandratos and Bruinsma 2012) and is projected to reach 133 kg/capita/year by the year 2022 (Punjabi 2010) and this has major implications for water use, as dry regions are producing maximum milk. The perceptible change in food habits of the people and the preference for finer varieties of grains would further increase the demand for water for agricultural production.

Some researchers argue that when the country becomes developed and with nearly 50% of the population living in urban centres, there would be more demand for water from manufacturing and urban sector and agriculture would be less important in India's economic landscape (see Amarasinghe et al. 2008). Some of them argue further that with income from the non-farm sector becoming important, fewer numbers of people from rural areas would be dependent on agriculture for their livelihoods with the result that the average farm size would increase and those who operate the land would be in a position to use modern farming equipment with a resultant positive impact on water use efficiency. They do not foresee national food security as a concern for investment decisions in the water sector, as they believe that food and feed can be imported. Along with food security, energy security is also essential. There is no thinking on how food and energy security can be concurrently achieved.

The situation in some developed countries, where manufacturing and domestic sectors account for a large share of the total water use (UN 2009) is often cited to support these arguments. Such optimisms are highly misplaced, and can lead to dangerous consequences for the country's food security, rural livelihoods and overall social fabric, resulting from widespread water shortages in rural areas owing to lack of investment for irrigation. The reasons are many:

First: India has a very large rural population and a very large workforce, and the potential of manufacturing and service sectors to absorb this population is very limited. The possibility of population stabilising before 2050 is impossible. As a combined effect, a significant chunk of the rural population would continue to depend on farming and allied sectors as one of the occupations for many decades to come. While there is no extra arable land available for cultivation, this would only lead to intensive use of the land that is under crop production by making more irrigation facilities. We also have to make big allowances for food waste, unless major reductions in pre- and post-harvest losses of agricultural produce are achieved in coming years. As global experience suggests, a major increase in farm size that is sufficient to make a significant impact on modernisation is unlikely to happen in the near future in India (Eastwood et al. 2010).

Second: a decline in food grain and agricultural production, with a simultaneous increase in per capita income can cause food price inflation, and there is also an inverse relationship between growth rate in food grain production and agricultural price index (Sasmal 2015). These relationships imply serious consequences of any future reduction in agricultural production for food security, hunger and poverty, because of two major reasons. (1) there are large regions in India, especially in the eastern Gangetic basin where the poverty rate is very high, and the population in that region is increasing much faster than the rest of the country, with an increase in absolute number of people living in abject poverty. (2) the purchasing power of an average person would be adversely affected by rising food prices. The combined effect would be that hunger would increase due to insufficient access to food (based on FAO 2009).

Third: unlike many developed countries, which have very good agricultural production technologies, large-sized operational holdings, very small fraction of the population engaged in farming with high average income of individual farmers and a lot of the agricultural outputs produced for export, in India, farmers who have very small average holdings and low average income, have very little leverage to reduce the area under production and reduce water use (Eastwood et al. 2010, based on 1990 and 2000 rounds of FAO farm measures; Wichelns 2003).

Some recent projections show growth in aggregate water demand in agriculture by the year 2025 (for details, see Amarasinghe et al. 2008; Kumar 2010). In many developed countries, the agricultural water withdrawal has increased over the years, in spite of water use efficiency improvements. An example is the USA (based on Kenny et al. 2009). In all probability, a similar trend in water use would be witnessed in India, which is most likely to experience large-scale adoption of water-saving technologies in water-scarce regions, owing to the presence of extensive well irrigation and the presence of large areas under crops that are amenable to micro-irrigation technologies. A major reason for this likely trend is that only 30–40% of the arable land in these areas is currently under irrigation and there is strong incentive among farmers to expand the area, using the saved water. Hence, due to excessive increases in irrigated areas, eventually consumptive water use would either remain the same, or even increase.

While these can be the probable trends of agricultural water demand in India, water demands in domestic and industrial sectors are going to increase at a very high rate, given the high rate of urban population growth and industrialisation. In future, domestic and industrial sectors would claim a greater proportion of the available water than at present. There would be great competition for the limited water resources from these sectors. Problems of food shortage and water scarcity are likely consequences, unless we increase crop yields substantially through technology innovations, improve efficiency of use of water Kilogram of biomass per unit volume of water consumed in evapotranspiration (kg/ET), and reduce the colossal wastage of agricultural produce, during and after the harvest. The need for promoting this three-pronged approach is as follows. First: in regions where there is enough water, there is huge scarcity of land. Second: in regions with plenty of arable land lying un-irrigated, water is a major constraint for crop intensification. Third: reducing food wastage would reduce the domestic demand for cereals at the aggregate level. Therefore, we would require an integrated approach to addressing the water-land-environment related issues. We are already seeing enormous investments in genetically modified (GM) crops, salt-tolerant crops, drought and flood resistant crops and high yielding seed varieties.

11.3 Can Water-Scarce Regions Adopt a Soft Water Path to Development?

Myth: Water-scarce regions can abandon intensive agriculture, and look for soft water path to development.

Reality: Water-scarce regions are agriculturally most prosperous regions, and water-rich regions are agriculturally backward. Also, number of people engaged in farming is more in the water-scarce regions. This is also true for countries such as the USA, Mexico and China.

Among the water demanding sectors of the economy, agriculture is still the largest user (Amarasinghe et al. 2008; Kumar 2010). Given the fact that our economy is still a developing one, with low average incomes, the size of agricultural GDP and the number of people engaged in agriculture in a region could determine whether agriculture is important for the region's economy or not. Figure 11.2 shows that per capita agricultural GDP is very high in regions that are naturally water scarce.

Historically, these states have seen irrigation expansion through both surface water development and groundwater development. Gujarat, which currently has low agricultural NSDP (Net State Domestic Product), is now experiencing a high degree of agrarian growth with the introduction of SSP (Sardar Sarovar Project) waters for irrigation. Whereas, the agricultural component of net state domestic product in per capita terms is very low for some of the water-rich states such as Bihar, Uttar Pradesh, Kerala, Assam, West Bengal, and many of the northeastern States (with the exception of Himachal Pradesh and Arunachal Pradesh). This is in spite of the fact that, there, states have a high degree of irrigation development. The reason for this dichotomy is that the marginal returns from the use of irrigation water are much higher in water-scarce regions, compared to water-rich regions Kumar et al. (2008a).

As regards agricultural labour, we do not find a similar trend, though. The number of persons employed in agriculture as a fraction of the total population of the state (Fig. 11.3), either in own farming or as agricultural wage labourers, is not high in the water-scarce states, except Madhya Pradesh and Andhra Pradesh. Most importantly,

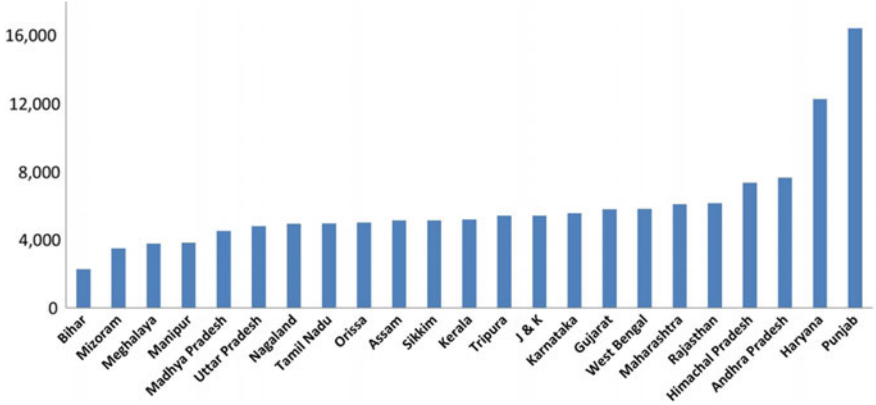

Fig. 11.2 Per capita agricultural GDP of selected states

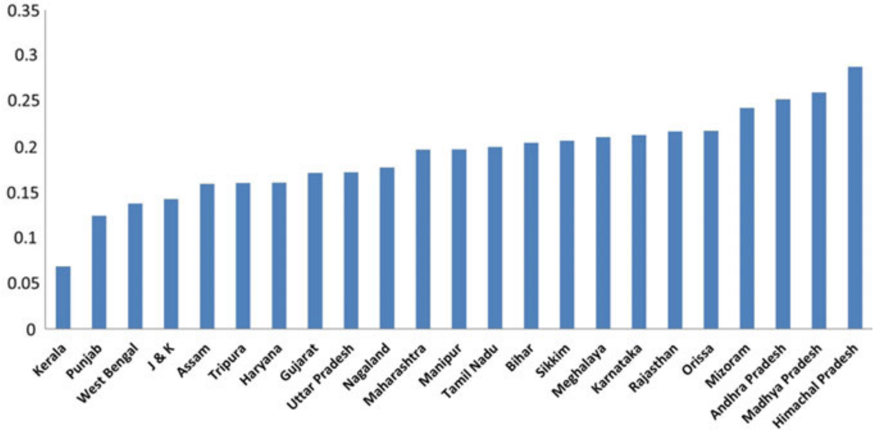

Fig. 11.3 Population engaged in agriculture as a fraction of total (2001)

the number of people engaged in agriculture as a ratio of the total population is very low in Punjab and Haryana in spite of these states having large irrigated areas, because farms in Punjab and Haryana attract a large number of migrant labourers from Bihar. For instance, in the case of Punjab, paddy cultivation alone attracts nearly 55.75 million person-days of migrant labour from Bihar (Kumar and van Dam 2013). Hence, the actual number of people that these states can absorb as agricultural labourers, is high. Whereas, in many of the water-rich states, such as Kerala, a small fraction of the population is engaged in farming, with the ratio below 0.07, meaning only 7 out of the 100 persons in the state are engaged in agriculture. In states, such as Bihar, where the percentage of people engaged in agricultural labour appears high, the actual figure could be much lower if we factor out migrant labourers who work in other states. While Bihar has highly fertile soils and abundance of water, what it lacks is sufficient amount of arable land in relation to its high population, and the per capita arable land in the state is very low (0.07 ha).

If water-scarce states such as Punjab, Haryana, Gujarat, Rajasthan and Madhya Pradesh moved out of agriculture, it could have serious consequences for rural employment and livelihood. In the case of states such as Punjab and Haryana, such diversification would also affect in the neighbouring poor state of Bihar, which exports labour. Whereas Kerala can still afford to move out of agriculture and has been able to do so through investments in education and human resource export to other parts of the country and the world, Kerala has also been successful in replacing traditional paddy with plantation crops (like coconut, arecanut, rubber) that require labour spread over the whole year, rather than seasonal labour, thereby avoiding peak labour demands. A significant chunk of Kerala's State Domestic Product comes from foreign remittances. The relatively high per capita incomes and the relatively low contribution of agriculture to the state NSDP, make such a shift easier. In summary, it would be impossible for naturally water-scarce regions of India to move rural people out of agriculture, and adopt a softer path to development.

11.4 Can Supplementary Irrigation with Rainwater Harvesting Enhance Water Productivity of Rain-Fed Crops?

Myth: In water-scarce regions, supplementary irrigation supported by local rainwater harvesting can enhance crop water productivity remarkably.

Reality: In India, supplementary irrigation is required mainly for kharif crops when monsoon fails.

Creating infrastructure for supplementary irrigation is too expensive. However, supplementary irrigation is already happening by default wherever technical feasibility exists. Alluvial Punjab, Haryana and alluvial tracts of Gujarat are examples. In other places (especially in the hard rock areas), there is a shortage of water in aquifers and local catchments for harnessing to provide for supplementary irrigation when it actually becomes critical for plant protection. Yield and water productivity of crops in physical terms may go up with supplementary irrigation, but outcomes *vis-à-vis* net return and water productivity in economic terms are open to question due to the high cost of harvesting water in situ for supplementary irrigation. The research from other parts of the world is rather skewed and largely ignores the economic viability aspects (Kumar and van Dam 2013).

This idea, however, has found many takers in India, who have extended it to the rain-fed areas of the country, where productivity of rain-fed crops is low (see Iyer 2011; Phansalkar and Verma 2005). Such skewed analysis has limited application when the farmers are concerned more with maximising the net income returns from a unit area of the farm or unit volume of water rather than the total grain yield from unit volume of water. The reason is that the cost of providing supplementary irrigation would be so substantial that it would significantly reduce the net returns and therefore water productivity in economic terms (Kumar and van Dam 2013).

To begin with, there are two types of rain-fed areas in the country. The first is high rainfall regions, where the monsoon rains alone can support the growth of kharif crops. Examples are high rainfall areas of Kerala, Jharkhand, Assam, Orissa and West Bengal and the eastern parts of Madhya Pradesh. Here, the dominant kharif crop, i.e. paddy, is fully grown under rain-fed conditions. The second is areas where the kharif crop is grown under dry conditions, just using soil moisture available from the rainfall. We would therefore deal with the second type of areas.

In water-scarce regions, supplementary irrigation to enhance crop water productivity would make sense if the incremental (net) economic returns from yield enhancement exceed the opportunity cost of depriving the downstream users of equal amount of water. So, there are two aspects to it: (1) the cost of providing supplementary irrigation against the incremental return farmers can secure through yield enhancement; and (2) the opportunity cost of using water for supplementary irrigation (Kumar and van Dam 2013).

If we leave aside alluvial areas such as Punjab and Haryana where water intensive crops are grown with supplementary irrigation resulting in high crop yields, everywhere supplementary irrigation is required when the monsoon fails, as farmers are already growing crops that are of short duration and that transpire less amounts of water. It is in this low to medium rainfall regions where monsoon rains experience high variability (Droogers et al. 2001). These regions also experience high aridity, and a significant part of the potential evaporation is during the monsoon season itself. As a result, in years of meteorological drought, the reduction in runoff would be disproportionately higher than that of the rainfall, leading to hydrological droughts. A close look at these regions shows that they fully coincide with those regions where groundwater resources are either scarce due to hard rock geology or are over exploited (Kumar et al. 2006). In the hard rock regions, the local groundwater supply being a function of rainfall, in drought years, water availability in the wells during monsoon would be poor. While supply of local runoff and groundwater would be extremely poor and unreliable, use of exogenous water is not going to make economic sense, as both the direct cost and opportunity cost would be too high.

Some advocate rainwater harvesting as an alternative to large water resource systems such as large reservoirs and canals (Dharmadhikary 2005; Iyer 2011). A recent work in India argues that the cost of water-harvesting systems would be enormous, and reliability of supplies from it very poor in arid and semi-arid regions of India, which are characterised by low mean annual rainfalls, very few rainy days, high inter-annual variability in rainfall and rainy days, and high potential evaporation leading to a much higher variability in runoff between good rainfall years and poor rainfall years (Kumar et al. 2006, 2008c), and are also very expensive. Comparison between the unit cost of water harvesting and recharge schemes, and net return from unit volume of water obtained in irrigated crop shows, incremental returns due to yield benefits may not exceed the cost of the system (Kumar et al. 2008c).

More importantly, since the basins in such regions are ‘closed’, the water-harvesting systems cause negative impacts downstream (Glendenning and Vervoort 2011; Kumar et al. 2008c; Ray and Bijarnia 2006). Due to high inter-annual variability in rainfall and runoff, the economic viability of water harvesting reduces with increasing system capacity (Kumar et al. 2006, 2008c).

11.5 Are Rain-Fed Crops Alone Sufficient to Boost Agriculture Production in the Future?

Myth: A lot can be done in the rain-fed areas to enhance agricultural production, merely by focusing on new rain-fed varieties.

Reality: Yes, but to a limited extent. Irrigation has been the key to enhancing grain production, and ensuring food security at the national level, with two-thirds of the agriculture production coming from irrigated areas. The following analysis supports this.

Analysis of data on state-wide per capita irrigated area and an agricultural component of per capita net state domestic product in India show that the agricultural GDP is strongly related to the irrigated area (the regression equation is $Y = 3457 + 40862 \times X$, where X is the area in hectares, and Y is the agricultural GDP in Rupees). The R^2 value was 0.75 here, meaning irrigation explains agricultural GDP to an extent of 74%. Such a strong relationship (in spite of the sample states having wide variations in agro climate from hot and semi-arid and arid climates to hot sub-humid climate and cold and sub-humid climate, and major variations exist in the percentage contribution of rain-fed area to total cropped area across states) shows the high impact of irrigation in driving agricultural growth irrespective of the climate. On the other hand, the very small Y intercept of the curve (3514), indicates limited contribution of rain-fed production to agricultural GDP. While the rain-fed area in relation to population size is very high in high rainfall regions of India such as Kerala, Bihar, Uttar Pradesh, West Bengal and Assam, the agricultural GDP per capita is very low in these states, which make the curve steep and its ‘Y intercept’ small. The very low per capita arable land in these states reduces the overall scope for enhancing rain-fed component of agricultural surplus.

The rain-fed yields in India are quite low, with a large difference between potential yields and actual yields realised in farmers’ fields (Rockström et al. 2007). The extent to which they could actually contribute to boosting India’s agricultural outputs in value terms needs to be thoroughly examined against the amount of water taken from the hydrological system. A study carried out in Narmada river basin showed that rain-fed crops accounted for nearly 79% of the total water used from the hydrological system for crop production (17.52 BCM against a total of 22.05 BCM), but contributed only 61.7% of the surplus value product from agriculture. Whereas blue water accounted for only 21% of the total water use, and constituted 38.3% of surplus water product from agriculture. The overall water productivity for blue water use was Rs. 2.5/m^3 while it was only Rs. 1.03/m^3 for green water use (Kumar 2010).

Droogers et al. (2001) show that the rain-fed yield potential in India is very low to moderate in the regions where the mean annual rainfall is the range of low to high. It is only in the very high to excessively high rainfall regions where the rain-fed yield potential is high. Kumar (2014a) shows that improving the yield and water productivity in rain-fed agriculture in central Indian belt and peninsular India would require supplementary irrigation along with improvements in other farm inputs, in the central Indian belt and parts of peninsular India, where the yield potential is very low to moderate. However, it was further argued that, in many cases, there are hydrological and geo-hydrological constraints in ensuring supplementary irrigation through small water harvesting systems in these regions.

In water-scarce regions, such comparisons of economic surplus generated from blue water and green water are extremely important. What is often not appreciated is that when basins are ‘closed’, expansion in rain-fed areas means reducing the stream-flows and natural recharge to groundwater, which could be made available for diversion into irrigated production that generate higher value surpluses (Falkenmark 2004). In other words, so long as there is an opportunity cost of using moisture in the soil profile for growing rain-fed crops, this trade-offs need to be fully understood (Kumar 2010).

Under such circumstances, to enhance agricultural outputs we should choose from each region, those rain-fed crops that yield highest water productivity (Rs/m^3), and also identify regions where a particular rain-fed crop gives highest water productivity. It would result in more water being available in the hydrological system as blue water, and take some land out of cultivation. Comparison of water productivity estimates for two rain-fed crops namely, soya bean and black gram, from nine districts representing seven agro climatic sub-zones in Madhya Pradesh shows that water productivity of Soya bean varies across agro climates from 0.68 Rs/m^3 to 2.68 kg/m^3 in a normal year to 0.85–1.83 Rs/m^3 in a drought year. Also, there was significant difference in water productivity between black gram and soya bean, with the former showing higher water productivity in the two zones where both the crops are grown—Rs. 3.55/m^3 against Rs. 2.08/m^3 in Hoshangabad and Rs. 1.34/m^3 against Rs. 0.68/m^3 in Narsinghpur (Kumar 2010). Conversely, if the basins are still ‘open’, we need to identify crops which, if provided with supplementary irrigation, can give higher net return from every unit of land, and devise strategies for supplementary irrigation.

11.6 Can Micro-irrigation Systems and Water-Efficient Crops Solve Irrigation Water Scarcity Problems?

Myth: Micro-irrigation (MI) can help expand the irrigated area manifold and can substitute investments in large water development projects. In water scarce regions, significant water saving in agriculture would be possible through shift in cropping pattern to highly water-efficient crops.

Reality: There are major limitations to expanding area under MI systems, induced by cropping pattern, soils, geo-hydrology and climate. There are also limits to expanding area under water-efficient crops, induced by concerns of farming risk; national and regional food security and labour absorption in agriculture.

The real water saving benefits of MI come from reduction in non-beneficial evaporation and non-beneficial, non-recoverable percolation (Allen et al. 1998). The reduction in non-beneficial evaporation through the use of MI systems would be significant only in the case of distantly spaced crops, and for arid and semi-arid climates. Increases in spacing and aridity increase this component of the total water depleted from irrigated land in the case of conventional flood or small border irrigation (Kumar et al. 2008b; Kumar and van Dam 2013). The non-beneficial non-recoverable deep percolation becomes major when the unsaturated zone is deep, and the climate is hot and arid (Todd and Mays 2005). In hot and arid climates, the groundwater table is generally deep with thick vadoze zone. From an economic perspective, the cost of the MI system reduces with increase in spacing of plants, and economic viability of MI system generally reduces for closely spaced crops. Finally, the conventional MI systems require pressurising devices to run. The MI systems become technically feasible under pressurised irrigation.

Analysis by Kumar et al. (2008b) shows that the crops which are amenable to MI irrigation India cover only 7.93 million ha from 15 major Indian states, and from this only 5.84 million ha is where the MI systems can make significant impact on water saving. The empirical basis for estimating this is: (1) the gross irrigated area under crops that are amenable to MI systems; (2) the percentage of net irrigated area under well irrigation in the respective states; and (3) basins where adoption of MI systems for crops would lead to real water saving by virtue of the geo-hydrology and climate.

Kumar et al. (2008b) analysed the impact of MI devices on aggregate water requirement for crop production in India. A total of six crops, for which country-level data on irrigated crop area are available (namely, sugarcane, cotton, castor, potato, groundnut and onion), were considered for estimating the future water-saving benefits of MI systems. The data on aggregate output from these crops were then obtained. Assuming that the same output for the respective crops is to be maintained in future, the future water requirement for growing the crops could be estimated by dividing the improved water use efficiency figures by the crop output.

The aggregate reduction in crop water requirement due to the adoption of drip systems was estimated to be 44.46 BCM. It can also be seen that highest water-saving could come from the use of drips in sugarcane, followed by cotton. This is the maximum area that can be covered under the crops listed in well-irrigated areas, provided all the constraints facing adoption are overcome through appropriate institutional and policy environments. What is important is that the estimated total water saving (44.46 BCM or 4.44 Million Hectare Metre (M ham)) is only 17% of the total water demand-supply gap (26.2 M ham) estimated for the year 2025. This figure would undergo upward revision as the area under high-value crops (fruits, vegetables and flowers) increases as a result of market pull.

As regards introduction of water-efficient crops (in terms of Rs/m^3 of water depleted), at the farm-level, replacement of traditional cereals (paddy and wheat) by water-efficient vegetables, fruits and cash crops would induce constraints from the perspective of farming system resilience, as raising these crops involves production and market risks, apart from being capital intensive (Kumar and van Dam 2013). In composite farming systems, dairying, which is dependent on crop by-products yield high water productivity (Amede et al. 2011) and replacement of cereals by fruits, vegetables and cash crops would affect dairy farming (Kumar and van Dam 2013).

At the regional level, attempts to adopt water-efficient crops or crop-dairy based farming to enhance agricultural water productivity might face several constraints from a socio-economic side. First, is the food security constraint (based on Amarasinghe et al. 2004; Ganesh-Kumar et al. 2007). However, this constraint would soon disappear with Madhya Pradesh emerging as a major supplier of cereals to the national grain bank.

Labour absorption capacity of irrigated agriculture and market prices of fruits are other considerations. Replacing paddy, which is highly labour intensive, by cash crops would mean reduction in farm employment opportunities. On the other hand, the labour and fodder scarcity would be constraints for intensive dairy farming to maximise farming system water productivity at the regional level, though some farmers might be able to adopt the system. Large-scale production of fruits might lead to price crashes on the market, and farmers losing revenue unless sufficient processing mechanisms are established. Hence, the number of farmers who can adopt such crops is extremely limited (Kumar and van Dam 2013).

11.7 Can Groundwater-Intensive Use Be the Panacea for Water Problems in India?

Myth: In future, India's irrigation will be entirely from groundwater, in lieu of the pathetic performance of public surface irrigation system, manifested by the zero growth in canal irrigated areas, despite the sector witnessing continued investments (Mukherji et al. 2013; Shah 2009). Though groundwater resources are over-exploited in some arid and semi-arid regions, these problems can be tackled through local recharge initiatives, and MI systems.

Reality: The crisis of the groundwater sector is far more serious than in the surface water sector. It is an institutional and governance crisis.

India faces the problem of excessive use of groundwater for agriculture in the semi-arid and arid regions, with many millions of small holders pumping groundwater through wells and pump sets (Kumar 2007; Kemper 2007). Groundwater overdraft problems are experienced in hard rock as well as alluvial areas (Anantha 2009; Narayanamoorthy 2015; Kumar 2007).

However, political economic considerations guided policies in the water and energy sector that had implications for sustainability of groundwater use for agriculture in rural areas. Farmers constituting a major share of the rural vote bank, the politicians' views are largely myopic. They consider measures such as raising power tariff and regulating energy supply in the farm sector as highly unpopular and suicidal, despite growing evidence to the effect that farmers prefer good quality power that is sensibly priced than free power, which is available over short duration (World Bank 2001). Instead, they prefer popular schemes such as 'small-scale rainwater harvesting' for villages, and frame policies and legislations to favour investment in such schemes.

The arguments that shaped public policies in the agricultural groundwater sector in India are: high density of farm wells in remote areas increases the transaction cost of metering and charging for electricity on pro rata basis, as a tool to control groundwater draft; groundwater economy is controlled by millions of small and marginal farmers, and that any attempts to regulate it would threaten their livelihoods and therefore are politically sensitive (Mukherji et al. 2012; Shah 2009); and, eastern Gangetic plains, which have abundant groundwater resources, can kick-start a second Green Revolution if electricity supply in the rural areas is improved and free power connections are offered to farmers, by intensifying groundwater use for irrigation (Mukherji et al. 2012).

The politicians and policymakers are also encouraged by some highly pervasive arguments from researchers such as: (a) free power and subsidised diesel benefit for poor small and marginal farmers who do not own wells, by lowering irrigation water charges in the market; (b) transaction cost of metering and introducing metered tariff would be so high that it, if passed on to the consumers in the form of an electricity tariff, would reduce the overall welfare benefits of groundwater irrigation, while substantially reducing farm incomes (Shah 2009); (c) raising the power tariff would adversely affect the poor water buyer farmers, by raising the selling price of water (Mukherji et al. 2012); (d) small water harvesting systems are cost effective, and improve water security in villages if built in large numbers, and have no negative social environmental effects (see for instance, Shah et al. 2009).

Large amounts of public funds are being pumped every year into integrated watershed management, dug well recharging, and community-based water harvesting in naturally water-scarce regions, without any hydrological considerations, and with no visible positive outcomes (Kumar 2007; Kumar et al. 2008b). However, there are no attempts to introduce market instruments such as electricity pricing or groundwater taxes or water rights.

Two decades of research in the groundwater sector also show that: (1) the regions with high well density do not experience intensive groundwater use; (2) the groundwater economy is mainly controlled by large farm; (3) in water abundant areas of eastern India, subsidised power does not reduce monopoly power of water-sellers (Kumar 2007); (4) in the eastern Gangetic plains, there is too little scope for raising cropping intensity from current levels through intensive groundwater use, as future growth in irrigation demand is unlikely owing to lack of uncultivated arable land, and free power connections will only benefit resource-rich diesel well owners, who sell water to the poor non-well owning farmers (Kumar et al. 2014); (5) in water-scarce regions, as the selling price of water reflects its scarcity value, increases in power tariff would have only marginal effect on the selling price of water (Kumar 2007); and (6) in semi-arid regions, raising farm power tariffs will not only result in improved efficiency, equity and sustainability in groundwater use, but will also be socio-economically viable (Kumar et al. 2013).

These studies further concluded that India would require strong institutions and instruments to check groundwater over-exploitation and to achieve greater equity of access to the resource and efficiency and sustainability of resource use. These can be in the form of water rights systems, and energy pricing and energy rationing, complemented by local institutional development for resource management, including monitoring of resource use (Kumar 2007; Kumar et al. 2013).

11.8 What Is Likely to Be the Future Trend in the Water Management Sector in India?

Even as the structure of Indian economy changes and per capita income rises, contrary to widespread belief, only a slight shift in the pattern of water use towards manufacturing and urban sector would be possible over the next few decades in India as per some projections (Alexandratos and Bruinsma 2012; Amarasinghe et al. 2008; Kumar 2010). This shift is not going to result in an aggregate reduction in water demand in agriculture, while urban and industrial water demands will grow manifold. On the other hand, with increasing remittance from cities and better access to knowledge and information through improved communication networks, the farm households might be able to invest more in agricultural technologies. This would be supported by the growing public expenditure in the farm sector, especially on subsidies for agricultural technologies that promote water use efficiency, crop protection and irrigation pump efficiency.

Keeping the foregoing analyses at the backdrop, the following are the mega trends that one would expect for India's water sector in the coming three to four decades, towards averting an impending water crisis and food shortage: (1) increasing state level regulation of water development in river basins; (2) greater number of inter-state water sharing agreements, and execution of large projects for transfer of water from water-rich basins to water-scarce basins; (3) large-scale adoption of micro–irrigation equipment, precision farming and plastics in agriculture for drastically improving water use efficiency, driven by the pressures of water scarcity and rising price of water; (4) adoption of new-age crop varieties—high yield seed varieties, salt-tolerant, and drought and flood resistant and GM crops; (5) greater regulation of groundwater over-draft through institutional development and application of market instruments; (6) large-scale investment in infrastructure and administration for demand management in urban areas, including leakage reduction, and water metering, pricing and rationing of water supplies; and (7) emergence of new institutional models for investment in wastewater treatment systems in cities. We will discuss these trends in the subsequent paragraphs.

With increased use of irrigation technologies, at the aggregate level, there would be reduction in demand for water in crop production (per unit area) as a result of improved water use efficiency. But, this is unlikely to result in water resource conservation and arresting of groundwater depletion in a majority of cases, as most regions that are likely to witness large-scale adoption of such technologies experience a relative scarcity of water when compared to land, with the result that the farmers would only expand the area under irrigation post-adoption, often called the 'rebound effect' of efficient irrigation technologies (Molle et al. 2004; Sanchis-Ibor et al. 2015).

Groundwater resources in India are already under severe stress due to abstraction exceeding utilisable groundwater recharge in most semi-arid and arid regions where it is the major source of water for irrigation and other uses (GOI 2012). The fact that the water-rich eastern India faces acute scarcity of arable land places additional pressure on land-rich regions to produce surplus for the former, while the latter have limited renewable groundwater resources. As regards surface water resources, in western and northwestern India and most basins of the South Indian peninsula (except Godavari basin), it is already over-appropriated, with some untapped potential in the central Indian basin of Narmada, which is considered in the ongoing plans.

The future development of water resources in India for irrigation expansion and other uses therefore cannot be driven by groundwater, but by surface water resources, mostly involving inter-basin water transfers. On the other hand, bringing about institutional reforms in the groundwater sector with the institution of water rights, and introduction of a resource fee and electricity pricing will be crucial for achieving sustainability, equity and efficiency in groundwater use.

These two steps would be crucial to enhance agricultural production, and to sustain the livelihoods of people in the rural areas of these regions. Gravity irrigation from surface schemes supported by large reservoirs is also essential to revitalise the over-exploited aquifers in these regions. The agreement is already signed between Uttar Pradesh and Madhya Pradesh for the Ken-Betwa link. Six links are under consideration from the Godavari river in Andhra Pradesh, to transfer water to Krishna and then to the Pennar basin areas.

Inter-basin water transfer is likely to gain prominence as it is one of the two strategic means for survival of the large cities located in the water-scarce regions (Mukherjee et al. 2010), the other being water demand management (Kumar et al. 2014). The situation appears grave when we consider that population growth in these large cities is far higher than in small towns (Kundu 2006). Apart from problems of quantity, many cities such as Chennai, Bangalore, Hyderabad, Pune, Bhopal, Delhi, Rajkot and Jaipur are facing acute shortage of good quality water for domestic and commercial uses. There are many Class I cities in south and western India with population in excess of 10 million, which are growing fast. The groundwater, which is used by residences and commercial establishments without treatment, to meet the deficit in public water supply, is heavily contaminated with minerals, and, in some cases, domestic and industrial effluent from cities and their outskirts. Hence, urban water utilities are left with no choice but to go for bulk transfer of surface water from water-rich areas.

While, in the past, measures to reduce urban water demand have been extremely limited. However, given the fact that new sources of supply are going to be highly expensive, there would be increasing efforts to go for technological solutions and institutional and policy interventions to achieve demand reduction, including leakage detection and reduction; metering and volumetric water pricing of water; and water rationing. Studies indicate that higher economic value would be realised through such transfers. But, such water transfers face social, political, financial, environmental, ecological, engineering and scientific issues (Kumar et al. 2008a), the most important being political in nature (Iyer 2008). The institutional regimes such as the inter-state water disputes tribunals are sufficient only for allocation of water of trans-boundary river basins.

But, as noted by Biswas et al. (2017), there are also several problems with the existing tribunal system for inter-state water allocation. First, there are no uniform, logical and common processes. They have considerable discretions in terms of processes to arrive at settlements as also underlying concepts under which settlements are made. Also, there were significant variations noticed in the fundamental assumptions used in working out allocations from one tribunal to other. Second, tribunal results are non-binding to the states. Third, the Central governments have been reluctant to establish institutions for implementing the awards. Fourth, there is no fixed timeframe for negotiations and adjudications (Biswas et al. 2017).

For inter-basin water transfers to become a reality, the current legal regime with regard to utilisation of water resources within the administrative jurisdiction of states, which have abundant water resources, will have to change for them to be under the purview of national laws. This can only enable speedy decisions for development and utilisation of these water resources. However, with the growing realisation that the water-rich regions will not be able to achieve food self-sufficiency with the arable land, ecosystem and production technologies at their disposal, political consensus is likely to emerge in future between potential ‘donor states’ and ‘receiving states’ on sharing of water. We can also expect greater application of economic principles in water management in future.

Here, the amount of water transferred by the donor states, and the amount of water required for producing one unit weight of food can be used as the basis for deciding the amount of cereals to be supplied to the ‘donor’ states, which are currently food insecure, by those which receive the water (Kumar and Singh 2005). The economic value of the water that presently comes free under ‘inter-basin water transfers’ can be used to decide on those subsidies at which cereals should be offered to the donor states. The initiative of the Union government to formulate a National Framework Law on water, particularly to address inter-state water disputes, would help address the concerns relating to inter-basin water transfers.

The riparian states of major basins, which have been on a war-path over sharing of water, are now showing increasing signs of willingness to have mutual dialogue to arrive at agreements on sharing of water and benefits of basin development, with the latest example of Telangana and Maharashtra signing an agreement over sharing of water from the Godavari basin.

Large-scale transfer of water to the cities would increase the volume of wastewater generated from those cities. The future would witness stronger institutional regimes in the form of regulations and a water pollution tax for improved water quality management in rivers, along with the creation of new institutions to build transparency, accountability and incentive among various line agencies involved in management of water supply to various sectors. Therefore, unlike in the past the urban water utilities would be under enormous pressure to treat the wastewater they generate, and put the water purchased through bulk water purchase agreements to use more efficiently.

The fact is that the water losses in distribution systems are very high in many cities that are spread over large areas; sewage collection is poor and separate systems for collection of stormwater and sewage do not exist in many cities (Kumar 2014b). Hence, in coming years, there would be enormous investment by urban water utilities in: (1) improving urban water supply infrastructure to reduce leakages, through replacement of old distribution systems; and (2) increasing the density of stormwater and sewage collection networks to improve urban drainage and improve the collection of wastewater, respectively.

While growing economic power would enable large cities to invest in improved water infrastructure (water distribution systems, drainage networks and sewerage system) and wastewater treatment technologies, it is quite likely that the treated water would end up in the peri-urban areas for producing fruits, vegetables, flowers and forage crops, on a much larger scale than what is happening today around many cities. Most of the farm produce, which comes from these areas ends up in the nearest cities for urban consumers. In Delhi and Kanpur, the municipal corporations are supplying treated wastewater to farmers in peri-urban areas at a fee (Amerasinghe et al. 2013). With greater willingness on the part farmers in naturally water-scarce regions pay for treated wastewater for irrigating these high-value crops, financially viable models in wastewater treatment and reuse would emerge in the future.

Hence, the future is likely to see public-private partnership for investment in wastewater treatment. Emergence of new institutional models in tandem with the greater willingness on the part of the urban population to pay for environmental management services are likely, with the result that the water utilities would be able to levy sewage treatment charges. This, in turn, can be diverted for building wastewater treatment systems. With skyrocketing of real estate prices in urban areas, the construction industry is also likely to invest in such systems even without the help of financing models, as this would help increase the market value of land in the peri-urban areas through reclamation of land degraded by wastewater reuse and a better living environment.

India's water bureaucracy's fascination for small water harvesting and watershed development seems to have already died out, with growing evidence to the effect that, in most instances, construction of water harvesting structures causes negative impact on overall water balance, in the form of reduced inflows into downstream tanks, lakes and reservoirs. While in the initial years, the irrigation/water resources department went against building water harvesting systems in the upper catchment of the reservoirs maintained by them, more recently, farmers, especially those who are dependent on tanks for irrigation, have started raising concerns about indiscriminate building of such structures. The increasing pressure from India's growing tax-paying middle class to invest in permanent water infrastructure is another compelling reason for this change in mindset. The future would also witness some sort of regulatory framework emerging with regard to water resources development in river basins/catchments.

However, to realise the goal of building large water infrastructure, Indian water administration will be forced to make investments in building a cadre of highly talented water sector professionals, to plan, design, execute and run the sophisticated water and wastewater treatment systems. This is going to be an enormous task, as over the past couple of decades, Indian water administration at both state and central levels had witnessed continuous loss of the 'talent pool' as people with vast knowledge, experience and collective memory retired from services and were not substituted by the induction of young professionals. Failing to achieve this task would create a situation wherein the governments and quasi-governmental agencies would be increasingly forced to outsource most of the work related to investigation, planning, design and management of water resources projects, to agencies in the private sector.

On the other hand, India would witness large-scale adoption of MI systems and other water saving practices like mulching for almost all the irrigated crops, barring a few, in the arid and semi-arid water-scarce regions, which are also agriculturally prosperous. On the one hand, the adoption would be boosted by the increasing preference of farmers for high value fruits, vegetables and flowers, driven by growth in demand triggered by growing urbanisation, increasing per capita income, and improved transportation facilities. On the other hand, it would be driven by social pressures to make agriculture more water efficient. Adoption of new-age crop varieties would contribute to this trend. This would help boost crop yields and improve water productivity in hot arid and semi-arid areas, but would be unlikely to save significant amounts of water from agriculture, owing to the fact that the scarcity of water is more acute than that of land in these regions, and farmers would eventually expand the area under irrigation. Sprinkler systems would account for a large proportion of the area under MI, and this trend would be part of agricultural mechanisation owing to reducing numbers of younger people in the agricultural workforce and rising farm wage rates. The phenomenon will have less to do with irrigation water scarcity. This likely increase in area under sprinkler irrigation systems is unlikely to result in saving of water even at the field level, as there would be no significant reduction in non-beneficial consumptive use and non-recoverable non-consumptive use for field crops.

Rural areas in the agriculturally prosperous, water scarce regions would require an enormous amount of talent for design, assembly, installation and maintenance of MI systems, other water saving technologies such as mulching and precision farming system, and marketing of new-age seed varieties, including that of GM crops. The increased demand for talented people, on the one hand, and the growing ability among farmers to pay for such services, would attract skilled manpower to rural areas.

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Chapter 12
Policy Options for Reducing Water for Agriculture in Saudi Arabia

Christopher Napoli, Ben Wise, David Wogan and Lama Yaseen

Abstract As populations and economies grow, a megatrend that will increasingly affect both developed and emerging economies is the policy trade-off between managing water resources and achieving food security objectives. This policy trade-off is very relevant in Gulf Cooperation Council (GCC) countries, which represent some of the most water scarce regions of the world and are also intent on achieving food security through domestic agriculture production. We offer a case study on the policy options for reducing water consumption while maintaining food security and farmer welfare in the GCC's largest country, Saudi Arabia. Specifically, we explore how crop substitution can reduce aggregate water use without compromising the current level of food security or farmer welfare. Additionally, we assess the potential social implications of crop substitution options in order to better understand the political feasibility of various policy choices. The results suggest that if water usage is to be minimised while maintaining food production and farmer welfare, then the primary candidates for reduction are crops or livestock with large water intensity and low revenue and/or low production. Eliminating these types of crops would yield higher water savings than moderate reductions across a large portfolio of crops at the lowest political cost.

Keywords Saudi Arabia · Water conservation · Food security
Linear programme · Political bargaining

12.1 Introduction

Water scarcity is typically defined as the ratio between a country's total freshwater withdrawals and its total renewable water resources (Brown and Matlock 2011). When a country withdraws less than 20% of its total renewable water resources it is considered to be water abundant. If extraction falls between 20 and 40%, it is

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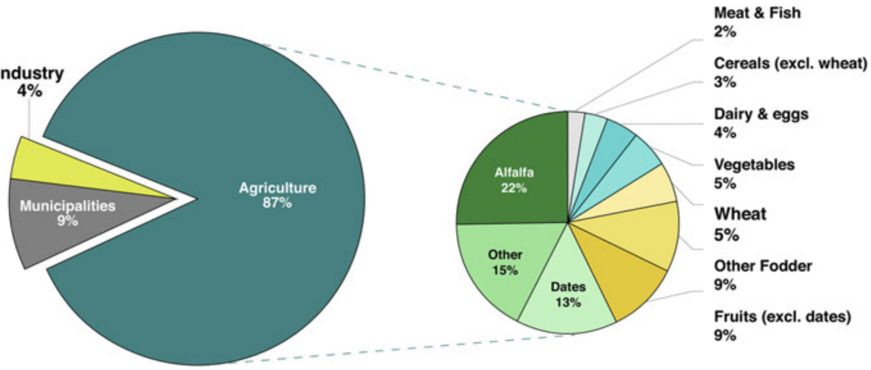

Fig. 12.1 Extracted water use in Saudi Arabia, 2010. *Sources* FAO (2015), Min. of Agriculture (2014)

considered water scarce; and when the ratio exceeds 40%, a country is considered *severely* water scarce. By this definition, Saudi Arabia is severely water scarce as the country is withdrawing an astounding 1056% (FAO 2015) of its total renewable water resources, meaning the country is not only relying on renewable water resources, but is also drawing heavily from its non-renewable fossil aquifers.

While Saudi Arabia has always faced a certain level of water scarcity, consumption levels were not always this high. In 1975, the first year for which water extraction data are available, Saudi Arabia withdrew 1.75 km^3 of water. This figure ballooned to 25 km^3 by 2006 (FAO 2015). The increase in water consumption was the result of two factors. First, the population of the country increased dramatically between 1975 and 2006 from 7.4 million to 25.4 million (World Bank 2015). Second, windfall profits from oil exports in the 1970s were used to finance large expansions of many sectors in the economy, notably agriculture. Today, agriculture consumes roughly 87% of all extracted water. As Fig. 12.1 shows, 31% of the water extracted is used to produce alfalfa and other fodder, which provide feed for the meat and dairy industries. Fruits (including dates), vegetables and cereals (including wheat) consume 35% of all water for agriculture. Given the percentage of water used by the agriculture system any attempt at improving the sustainability of water resources needs to include a reduction in agriculture consumption.

Saudi Arabia's extreme water scarcity makes it a sub-optimal location for agricultural production. Despite this, the rationale for supporting a domestic agriculture industry is twofold. First, the country is attempting to safeguard its food security by ensuring that an adequate amount of diverse foods are produced domestically (Lippman 2010). For certain fruit, vegetables and cereals, food self-sufficiency goals have been met and the country exports surplus production (Al-Shayaa 2012). At the aggregate level, however, results are varied. Self-sufficiency levels (i.e. the ratio of domestic production to overall consumption) differ for several agricultural commodities produced: vegetables (88%), fruit (57.4%), meats (41.2%) and cereals (7.4%) (Ministry of Agriculture 2014). While these self-sufficiency levels exceed other Gulf countries, they are lower than much of the Middle East and North African region (Sadik et al. 2014). At the aggregate level, the Food and Agriculture Organisation of the United Nations (FAO) food and agriculture database estimates that Saudi Arabia's total agriculture self-sufficiency ratio is roughly 25% (FAO 2015).

The FAO defines food security as "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (2002). From the perspective of a country like Saudi Arabia, food security is more of a risk-management issue than a structural inability to meet the needs of families, the problem in many low-income nations. Although defining the risks and their properties is central to developing an optimal risk-management strategy, here we rely on the quantity definitions used in Saudi Arabia to evaluate and compare policies using the measures the government has chosen.

A country can provide its population with food security in several ways. The most direct way is to support domestic production. Alternatively, it can import agriculture products from a diverse portfolio of suppliers from different parts of the world. While diversifying supply may increase costs over purchasing large quantities at discounts, this strategy would protect against production problems in a single country or shipping disruptions. A country could build a strategic reserve of storable crops. Additionally, food security can be improved through purchasing agriculture land or agri-food companies located abroad to influence the direction of food trade. Saudi Arabia has engaged in the first and last methods: the country has bought working farms in Poland and the Ukraine through the Saudi Agricultural and Livestock Investment Company, and, in 2015, the country became a large investor in the Canadian Wheat Board (Bunge and King 2015). Despite cost-effective alternatives, there is still the presumption that a certain share of Saudi Arabian agriculture production should be produced domestically, which is why this chapter focuses on options for achieving this domestic production while reducing water use.

The second reason for supporting domestic agriculture production is that, as with much of the world, the agriculture industry is politically and socially sensitive (Sen 1982; Moench 2002). This industry provides employment and income, particularly in rural regions, and certain agricultural products, such as dates, are culturally significant. The government supports the agriculture industry with a range of implicit and explicit subsidies to make the industry profitable, even though it may be unsustainable in the long term. Examples of subsidies include the following: interest free loans and grants to farmers by the Saudi Arabian Agricultural Bank; government subsidies for livestock and poultry feed as well as farm machinery and equipment; government funding to support research aimed at developing new crop strains with greater resistance to pests; government expenditures to improve roads linking producers with consumer markets; effectively no tariff on water and very low tariffs on energy; and commodity boards such as the Grain Silos and Flour Mills Organisation, that agree to purchase grains and cereals at guaranteed prices irrespective of international market tariffs (Mousa 2015). The effects of these types of market distortions are seen in the difference between the price at which certain commodities are sold and their true cost of production. For example, the water required for a 1 Riyal loaf of bread costs 2 Riyals to produce (Vincent 2008).

Government intervention in setting prices is not unique to the agriculture sector. Other sectors that are important to the country, such as the power and water sectors, experience both administered prices for fuel inputs and regulated prices for electricity and water. These market distortions lead to investment in less efficient power and water infrastructure, and high domestic consumption of resources.

The quest for food self-sufficiency has had negative effects on the sustainability of groundwater resources (Al-Shayaa et al. 2012). The government recognises the unsustainability of current trends and has responded with two government policies. First, the Council of Ministers Resolution No. 335 of November 19, 2007 mandated the phasing out of domestic wheat production by 2016. It also abolished import tariffs on cereals, animal feed, and wheat flour, and reduced the general tariff on foodstuffs from 75 to 5% (Woertz 2013; World Trade Organisation 2011). Second, in 2010 the Saudi Arabian Ministry of Agriculture set a target of a 30% reduction in water usage in the agriculture sector by 2030 through improving irrigation techniques and eliminating water-intensive crops, and this figure may be increased to 50% (Jeffreys 2011). These two policies represent megatrends in the Kingdom specifically, and the Middle East in general where other Gulf Cooperation Council countries are also exploring ways to reduce water use while maintaining food security.

We use a simple linear programme model to explore the different ways the Saudi Arabian Ministry of Agriculture can meet its water reduction objectives without further compromising food security or farmer revenues. The results suggest that there are several options for reducing agricultural consumption by the 30 and 50% objectives, but that in each case, certain large water-intensive crops must be substantially reduced or eliminated. For each option, the water reductions translate directly into energy savings—with the amount of energy saved being a function of where the actual water reductions occur. This is an important consideration for two reasons. First, Saudi Arabia has exceptionally high energy use at 7.8 tons of oil equivalent per capita, which translates into significant carbon dioxide emissions and financial costs for the country (British Petroleum 2015; General Authority for Statistics Kingdom of Saudi Arabia 2015). Second, because water and energy production are inextricably linked due to their joint production by cogeneration plants, moderating energy use can provide a strong incentive to reduce water consumption.

In Saudi Arabia, the “two birds with one stone” rationale is often used when arguing for the construction of additional thermal-powered desalination plants. Effectively, with electricity demand on the rise, building additional electricity plants is easily justified. Because desalination plants can be built as part of an electricity generation plant with limited additional expenditure, it is often incorrectly assumed that building water and electricity cogeneration plants are a cost minimising way to meet both needs. This logic is incorrect for two reasons. One reason that thermal desalination costs (when built as part of a cogeneration plant) are perceived as low is that waste heat from electricity production is used to supplement the energy required for desalination. But, excessive waste heat often exists because electricity plants are deliberately built inefficiently to meet the desalination energy needs. This inefficiency increases the true cost of electricity generation, even if it decreases the costs of water production, with the net effects being higher costs for the government as both water and electricity are highly subsidised.

Second, desalination requires substantial energy even when supplemented by waste heat. As a result, desalination from cogeneration plants ends up increasing aggregate energy use, which justifies the need for more electricity. This continues the vicious cycle of building more cogeneration plants. Given this, reducing water consumption can have a direct impact on electricity requirements, and so it important to consider how water is used by society, and how electricity demand can be reduced through water conservation.

Building on these findings, we explore the potential political and social implications of the portfolio of crops produced under the different water reduction strategies. The results suggest that politically palatable options exist, and in some cases, it may be more socially acceptable to eliminate a few large, water intensive, low-value added crops than to reduce multiple medium value added crops.

12.2 Description of Data and Model

12.2.1 Data Sources

Table 12.3 in the Appendix contains data on the production of crop and livestock goods, water footprint, and monetary value of goods in Saudi Arabia. The data were compiled from reports by the Saudi Arabian Ministry of Agriculture (2014), the FAO (2015) and the Arab Organisation for Agricultural Development for 2013 (2013).

Blue water footprint values were used to calculate the irrigated water used to produce the respective agricultural products (Mekonnen and Hoekstra 2012). Due to missing water-footprint data for some products, assumptions were made by either using aggregate data or extrapolating water footprints from countries with comparable climates and growing conditions.

12.2.2 Water Minimisation Model Description

We constructed a linear programme to analyse the trade-offs in water consumption in the agriculture and livestock sectors for a range of policy scenarios. We chose a linear programming model as a first-order assessment of how the agriculture system balances three primary components: water consumption, revenue and total quantity produced. Data for these components are readily available at the national aggregate level and provide sufficient insight into the effect of different crop portfolios on water consumption. Because there are many subsidies to ensure that products sell at desired prices, rather than at competitive market prices, we did not consider input prices as part of the decision to produce a crop or not. A second-order assessment might use a mixed complementarity problem to model prices and quantities, which can adjust within administered ranges. This formulation has been used to investigate the role of industrial input prices for the power and water sectors (Matar et al. 2017). A similar formulation could be applied to Saudi Arabia's agriculture sector.

The model covers roughly 80% of all water used by the agriculture sector. The objective is to minimise water consumption while maintaining producer revenues (aggregate monetary value of all goods produced) while not compromising food security (measured in terms of total tonnage of all goods produced).

The objective function minimises water consumption:

$$\min_{W} = \sum_{i} (Q_i * w_i) \tag{12.1}$$

where Q_i is the production quantity in tons of crop i and w_i is the water use per ton of crop i produced. Baseline quantities and prices are Q_i^0 and P_i^0. Two constraints require a minimum level of farm revenue (12.2) and a minimum total production (12.3):

$$\sum_{i} \left(Q_i^0 * P_i^0\right) \leq \sum_{i} (Q_i * P_i) \tag{12.2}$$

$$\sum_{i} Q_i^0 \leq \sum_{i} Q_i \tag{12.3}$$

where P_i represents the price paid to farmers per ton of crop i in constant 2005 US$ and Q^i represents the volume. The next three constraints set limits on the production of individual crops. Two constraints limit production increases and decreases from 2013 levels (Eqs. 12.4 and 12.5) and a third requires the production of fodder to supply livestock demand (Eq. 12.6).

$$(1 - r_i) * Q_i^0 \leq Q_i \tag{12.4}$$

$$Q_i \leq (1 + g_i) * Q_i^0 \tag{12.5}$$

$$\sum_{\text{fodder}} (Q_{\text{fodder}} * f) \geq \sum_{\text{livestock}} Q_{\text{livestock}} \tag{12.6}$$

The terms r_i and g_i are the rate of decrease and increase for individual crops and are defined in the different scenarios.

Three crops are used as fodder for livestock: alfalfa, clover, and other fodder (which includes other forage crops produced in small quantities). The ratio of fodder to livestock (including dairy goods) is fixed, such that an increase in livestock production would require an increase in fodder for that livestock. The ratio of livestock to fodder, f, was calculated from the current baseline ratio (100 tons of fodder to produce 81 tons of livestock).

An alternate fodder to livestock ratio was calculated for the scenario where 400,000 tons per year of fodder currently grown domestically by Almarai are imported (Almarai Farming Division 2010). This ratio is considered because of recent policies by the firm to move away from a reliance on domestically grown fodder. With planned import increases, the new ratio becomes 91 tons of livestock for 100 tons of fodder.

The model reaches a water-minimising solution by choosing crops with the most weight per cubic metre of water until they reach their individual upper limits (by maximising production of the most valuable goods in US$ per cubic metre of water required).

12.2.3 Policy Scenarios

We designed a set of scenarios to analyse the trade-offs in water consumption for different production portfolios. We constructed 28 scenarios to explore a range of potential policy, but we will discuss only the 10 most illuminating scenarios in this paper. The configuration of these 10 scenarios are presented in Table 12.1.

For each scenario, we set the variables defined in Eqs. 12.4–12.6. First, we define upper and lower bounds on crop production. Depending on the policy, individual crops (or groups of crops such as dairy products) may increase or

Table 12.1 Policy scenarios for linear programming model

Scenario	Production decrease (%)	Production increase (%)	Fodder requirement	Wheat	Dairy	Dates
1	25	100	0.81	Variable	Variable	Variable
2	25	100	0.91	Eliminated	Variable	Fixed
3	25	100	0.81	Eliminated	Variable	Variable
4	25	100	0.91	Eliminated	Variable	Variable
5	25	100	No requirement	Eliminated	Variable	Variable
6	75	200	0.81	Eliminated	Variable	Fixed
7	25	100	Eliminated	Eliminated	Variable	Fixed
8	95	300	No requirement	Eliminated	Variable	Fixed
9	75	300	No requirement	Eliminated	Variable	Variable
10	95	300	Eliminated	Eliminated	Eliminated	Variable

decrease within the bounds by changing the variables r_i and g_i. As crops that have high water intensity per ton are removed from production, less water-intensive crops are produced to meet the revenue and food security needs. This setting also affords the model flexibility to find an optimal portfolio rather than restricting it to a narrow set of options.

Next, we select the role of fodder in livestock production. The ratio of fodder required to produce livestock can be set to the values described above. In Scenarios 5, 8 and 9 fodder and livestock production are decoupled, meaning fodder can be produced but it is not required for livestock. Fodder was eliminated in Scenarios 7 and 10 to reflect a situation where fodder was not produced domestically and must be imported. Finally, we select three crops (wheat, dates and dairy) that are either water-intensive or culturally significant.

12.3 Results

Several options can reduce water usage in agriculture without compromising food security or aggregate farmer revenues. Specifically, the results offer four insights. First, Figs. 12.2 and 12.3 demonstrate that water usage can be reduced by roughly 15% (or 3 km^3) with only minimal changes in the portfolio of crops produced, as demonstrated by Scenario 1. In this scenario, production of dairy and fodder products are slightly reduced and replaced by higher value-added vegetables and fruit. This scenario, however, likely understates the potential for water reductions as

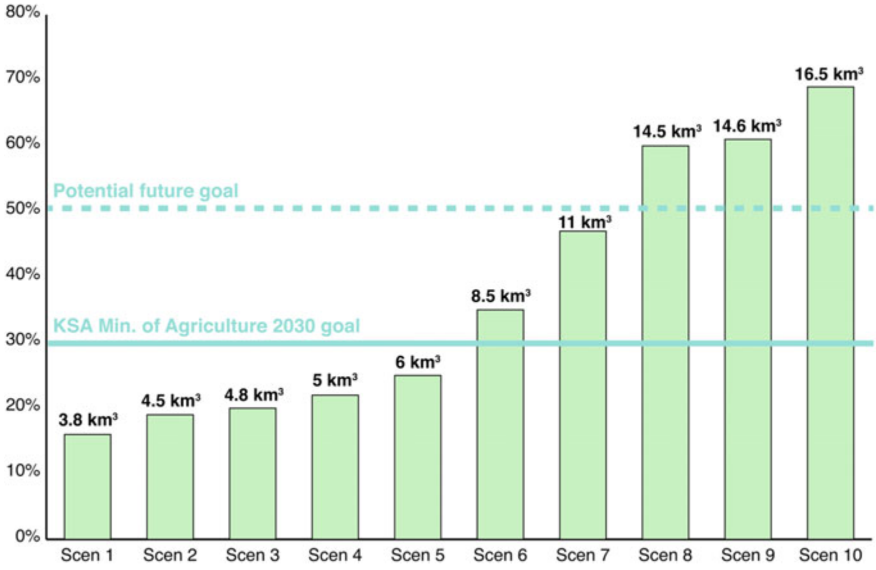

Fig. 12.2 Potential water savings from crop switching

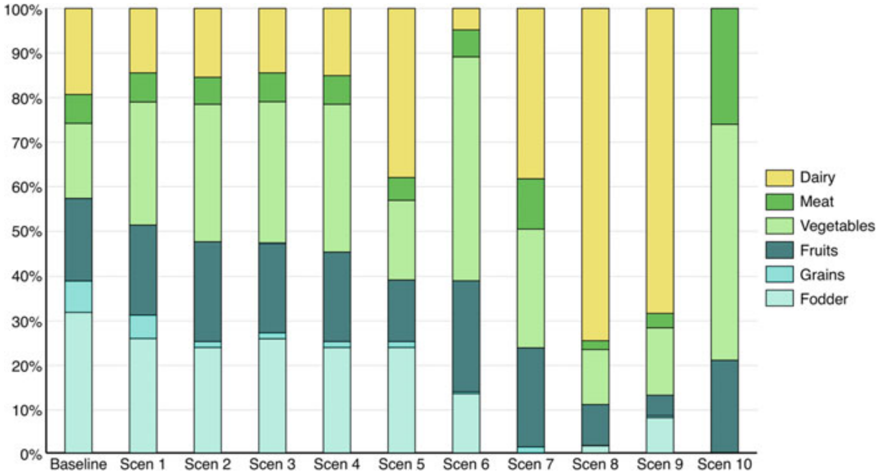

Fig. 12.3 Crop mix from the different scenarios

it does not include Saudi Arabia's commitment to eliminating wheat production by 2016. When the elimination of wheat is included, as is the case in Scenario 3, water savings rise to 20%.

Second, the results show that meeting the 30% water reduction objective requires a more ambitious strategy, such as those offered by Scenarios 6–10. In each of these scenarios, at least one of two changes is required: there must either be large changes in the quantities of the crops produced; and/or some of the highly water intensive crops must be eliminated. It should be noted that Scenarios 6–10 result in some significant changes to the portfolio of crops produced. For example, in Scenario 6 fodder and dairy production are substantially reduced while vegetable production more than doubles. In Scenarios 8 and 9, dairy production increases substantially while all other production is reduced.

Third, the potential 50% water-reduction target is possible only with substantial changes in crop production *and* the elimination of water-intensive crops. For example, Scenario 8 requires the elimination of wheat and substantial reductions in fodder, while scenario 10 requires the elimination of wheat, fodder and dairy. In practical terms, both substantial reductions and elimination yield the same result for water-intensive crops, as the model will reduce those crops to the maximum allowable limit. For example, in Scenario 8 alfalfa is reduced by 95% while in Scenario 9 it is reduced by 100%. Thus, the elimination (or virtual elimination) of these high-water-intensive crops is a prerequisite for large water savings.

Finally, the results show that large reductions in water can be achieved through different combinations of crops. In Scenarios 8 and 9, the portfolio of crops is dominated by dairy production at the expense of meat and fruits, while in Scenario 10 dairy production is eliminated and vegetables, meat and fruit make up the total portfolio. Although each scenario meets the objectives of reducing water use while maintaining farmer revenues and food security, the choice of scenario adopted depends on certain political economy considerations. These are discussed in the next section.

12.3.1 The Effects of Reduced Water Consumption on Energy Use

The potential effects of reduced water consumption on energy use depends on the source of the water being saved. Figure 12.4 shows that the total energy required to extract water from the surface, ground and desalination is just under 200,000 barrels of oil per day. Note, in the case of ground and surface water, only energy for extraction (and not treatment) is included, and in all cases energy for water transport is not included. Thus, this estimate does not include the total energy required to meet water demand in the country. Reducing water use by 16.5 km^3, the result of Scenario 10, would reduce energy consumption by roughly 40%. This result, however, assumes that the water reductions occur only where the water is currently being extracted (i.e. ground and surface water). However, as Fig. 12.4 shows, roughly half of the energy is used to desalinate 1.3 km^3 of water. If the ground and surface water saved were used to displace a portion of the desalinated water produced in the country, far more energy could be saved from water reductions. Given the extraordinary water scarcity in the country, it is unlikely that desalinated water would be eliminated, even if agriculture production was significantly reduced. Despite this, Fig. 12.4 shows the potential energy savings from reducing water where the marginal cost of energy is the highest.

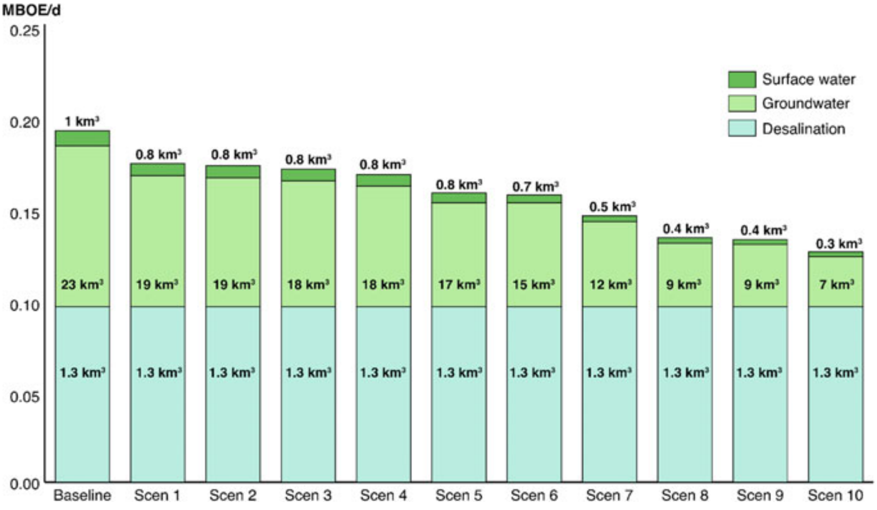

Fig. 12.4 Potential energy savings from water reductions

As stated above, these energy savings can have a direct impact on the justification for building more thermal desalination plants, which have traditionally been built as cogeneration plants used to satisfy both water and electricity needs. Reducing electricity demand lessens the need for future cogeneration plants, decreasing the justification for building desalination plants.

12.4 Collective Choice Model

In determining where to cut back or increase agricultural production, the scale of the farming of the different crops and cultural importance of certain crops are factors one would want to consider. We use a model that weighs a set of factors based on group-decision-making models. This allows us to bring together the heterogeneous interests of the farmers of different crops to assess the values of the different scenarios. A reasonable policy choice is likely to be close to what the players would negotiate among themselves. Thus, we examine the plausibility of potential outcomes as if the farm sectors were engaged in a negotiation among themselves.

The model is described in three sections. First, the underlying theory of collective decision making is summarised. The second section describes the estimation of utility based on changes in revenue. Finally, a method for giving the sectors importance weights is presented, which forms the core of this application.

12.4.1 Theory of Collective Choice

Since the outcomes of group decisions often lead to winners and losers, there is no group utility function like the individual utility function of economics. This lack of utility function has led to the study of non-cooperative and cooperative game theory and a literature on group choice. The formal study of group choice can be traced to Caritat, the Marquis de Condorcet, over 200 years ago (Caritat 1785). Caritat introduced the fundamental notion of a "Condorcet Winner", which is the option the group would take over any alternative option (if every pairwise comparison can be made [options are feasible or not, not their comparisons]). A common-sense property of a person's assessments of options is that if option A is preferred to option B, and option B is preferred to option C, then A should be preferred to C. Caritat discovered that the simple "one person, one vote" system usually produces incoherent collective choices in the sense that the group often has cyclic preferences where outcome A is preferred to outcome B, B is preferred to C, and C is preferred to A: no Condorcet winner exists.

Arrow extended this to Arrow's Impossibility Theorem (AIT) to state that, under a few common-sense conditions, no voting system is guaranteed to always produce non-cyclic group preferences (Arrow 1950, 1951). Both these results, and many other of the so-called ‘chaos theorems’ assume a model of formal, discrete ballots (Coughlin 1992). They have no measure of degree of preference or of influence, and they use only qualitative, yes/no preferences. Thus, they are not directly applicable to situations where a few actors have much more power to determine the outcome than do other actors. Differing levels of influence were introduced independently by Zermelo and by Hotelling and elaborated in Black and Downs under the assumption that policy choices could be represented as points on a one-dimensional scale and that the group would take the Condorcet Winner under weighted voting (Zermelo 1928; Hotelling 1929; Black 1948; Downs 1957). These results have been generalised to multi-dimensional choices, such as the choice of multiple production targets for different agricultural sectors (Wise et al. 2015).

These models are idealised in that they assume deterministic voting in the sense that even a tiny advantage would guarantee victory. For example, an 11:10 committee vote would produce a clear victory for the first option, albeit by only one vote. While this is a reasonable model for formal committee votes, less formal means of influencing an outcome do not have such clear-cut results because random events and influences can always occur. For example, the relative influence of advisors might be estimated from their years of seniority or the number of followers in the public at large, but such comparisons of potential influence are by no means precise. Similarly, if two competing groups spend US$11 million and US$10 million to raise public awareness of an issue, the first does have an advantage, ceteris paribus, but the result would be by no means guaranteed. Such informal exertion of influence is generally called “informal voting”, even though no formal system of ballots or scoring is involved. To model less-than deterministic group choices, we used the probabilistic choice model outlined by Bankes and Wise (2015), which draws upon the models outlined by Becker (1983), Enelow and Hinich (1990), Coughlin (1992), and Berger (2010).

12.4.2 *Utility Estimates*

The procedure above relies on estimates of the utility of each outcome to the actors. One obvious candidate for this utility function is the revenue in each agricultural sector, and the percentage revenue lost due to water reduction. To achieve the von Neumann utility scale revenues, we rescale from raw values so that the scenario with the lowest revenue has value 0 and the best has value 1, as in (Eq. 12.7). Let the scaled value of scenario s for actor i be $V_i(s)$ and $R_i(s)$ be the raw value for scenario s. The index j refers to the set of scenarios:

$$V_i(s) = \frac{R_i(s) - \min_j R_i(s_j)}{\max_j R_i(s_j) - \min_j R_i(s_j)} \tag{12.7}$$

As is well-known from finance, actors are always risk-averse to one degree or another when nontrivial amounts are at stake: they demand a positive risk premium to compensate for exposure to more risk, even when the expected value stays constant. It is well-known that, as the risk of an investment increases, the interest rates on financing it also increases, which again reflects risk-aversion. Mathematically, this corresponds to a utility curve which is increasing, but at a decreasing rate. One simple way to model the utility function $U_i(s)$ is with a simple quadratic curve that matches the end points at 0 and at 1:

$$U_i(s) = 1 - (1 - V_i(s))^2 \tag{12.8}$$

12.4.3 Influence Estimates

A standard first estimate of an actor's influence/importance to the outcome of a negotiation is the net wealth controlled by that actor. These weights are often called Negishi weights (Negishi 1972). While there is a debate as to whether these weights should be used in normative analysis, there is little debate that wealth and power are positively correlated. Therefore, we use the revenue in each agricultural sector as the initial estimate of informal importance.

In collective decision making, outcomes are uncertain because the major interactions occur informally, before formal decisions are announced. This is illustrated in stockholder votes in corporate takeovers when both sides aggressively solicit votes, even though majority rules once the votes are cast. Similarly, the outcome of informal discussions in councils might turn on the seniority and respect of various actors. The way uncertainty is reflected in modelling a negotiation is to compare the support enjoyed by two different proposals (Wise et al. 2015).

In the case of Saudi Arabia, the importance weights must be adjusted to reflect the national importance accorded to certain products. The production of dates, which are culturally significant for the country, is likely to be maintained. Similarly, wheat production is in the process of being eliminated, suggesting a very low level of exercised influence to protect wheat production. We adjust the importance weights as little as possible to assign high plausibility to the two observed policy choices. This is entirely analogous to the procedure in econometrics where the model parameters are tuned so that the estimated probability of the observed economic choices are highly likely, given the fitted parameters. The algorithm seeks a minimal set of adjustments to simultaneously meet two conditions. The first condition is that, without any influence of the goal to reduce water usage, the current situation is assigned a probability above a pre-specified threshold. The second condition is that, with influence for water minimisation, the announced policy for water minimisation is also above the threshold. Results for selected crops are listed in Table 12.2.

Table 12.2 Selected Negishi weights

Group	Initial	Fitted
Water reduction	–	1,114,490
Alfalfa	744,646	414,950
Other fodder	369,065	205,660
Dates	558,531	311,238
Milk (cow)	602,330	384,328
Meat (chicken)	857,680	1,487,605
Tomatoes	201,452	36,827
Meat (cow)	469,800	299,765
Eggs	199,954	127,584
Milk (sheep)	26,520	1,731,450

12.4.4 Evaluation of the Scenarios

Several results stand out. The first is that the mid-range water-reduction plans are the most strategically advantageous (Scenarios 4 and 7). The initial expectation was that small water reductions would be more strategically palatable than larger ones, but this turns out not to be the case. Upon examining the data set, the reasons are clear. If water usage is minimised while maintaining gross revenue and production, then the primary candidates for reduction would be those with large water usage and having low revenue or low production or both. The production of fodder for livestock fits this description. However, the nominal policy case includes a constraint that sufficient fodder be produced in the Kingdom to supply the needs of livestock in the Kingdom, while an alternative policy is identical except that the fodder constraint is removed, meaning that fodder is purchased from overseas. Keeping the fodder constraint does allow some water savings, but much greater savings are obtained by dropping the fodder constraint. Dropping the fodder constraint means that a great deal of water can be saved with little impact on revenue. This is strongly favoured by the water-minimisation actor, while the additional revenue and production is favoured by virtually all the actors except fodder: it produced significant gains at no cost for all actors except the weak fodder producer.

To examine the sensitivity of these results, the threshold probability of the nominal policy scenario was lowered in steps from 80 to 50%, as seen in Fig. 12.5. The vertical axis is a dimensionless probability: low probability indicates most expected difficulty in implementation. The horizontal axis is an enumeration of scenario options, sorted from least water reduction on the left to most reduction on the right.

In each case, moderate water savings remains the most likely result. As the distribution is flattened, the most likely policy outcome is pushed down and the second most likely outcome was raised, but the graph did not qualitatively change shape.

A second result is that while some of the fitted weights are roughly as expected, some are opposite the expected value, as seen in Table 12.2. As expected, the

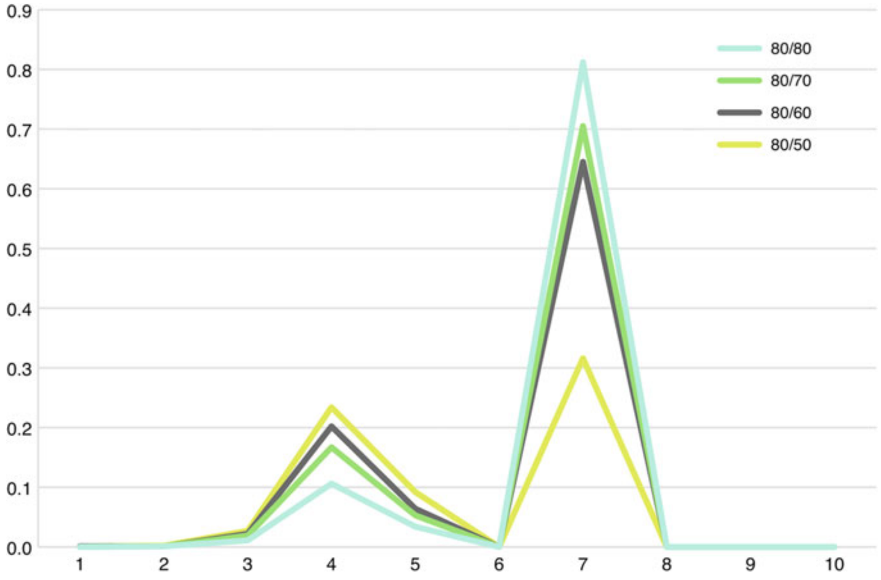

Fig. 12.5 Sensitivity of water reduction to changes in likelihood of nominal policy scenario

strength of the water reduction interest was one of the largest. As expected, alfalfa and other fodder were rated as weaker than their initial Negishi weights would suggest.

However, dates are fitted to be slightly weaker, while chicken meat and sheep milk are much higher. This result comes from the constraint limiting change to these products. If water were to be minimised, production of chicken meat and sheep milk would be greatly cut, but the limited-change constraint prevents that outcome. Therefore, those producers are assigned higher weight, reflecting their ability to limit the change in their production and avoid deeper cuts.

12.5 Limitations of Modelling Tools for Policymaking

The economic and policy models presented are powerful tools that can support the decision-making process, but do have limitations. Both models build on a large body of theoretical and empirical work, which means that a thorough discussion of their limits would be beyond the scope of this short chapter. However, we outline some of the limitations.

The linear programming model for water minimisation does not include the effects of changing prices on supply and demand; it only looks at the technical requirements of production. It does not include the potential for making investments to introduce a range of unconventional methods or technologies that could significantly reduce water consumption (e.g. aquaponics). More generally, the uncertainty of future demographics or technology—and adjusting plans in response to the changes—are not considered. Further, the linear programme does not look at the distributional aspects of policies (i.e. the social justice implications of their differing impacts on different segments of society).

The policy implementation model is analogous to a macroeconomic model, not to a microeconomic model or a detailed project-planning tool. Thus, it looks only at the large-scale balance of influence, not at the detailed tactics of “selling” any policy to either the public or to elite decision makers. Further, it assumes that (especially in a heavily regulated economy) that influence on future economic policy is highly correlated with past ability to capture value added.

A holistic approach to addressing the water-energy-food nexus through policymaking would also include qualitative assessments about challenges with implementing policies, unintended consequences, spillover effects on other industries or stakeholders.

12.6 Conclusions

Saudi Arabia is a severely water scarce country. Much of the water extracted is used by the agriculture sector, which is strategically important given the country’s food security and social (rural employment) objectives. We use a simple linear programming model to explore the different ways water reduction objectives could be met without further compromising food security or farmer revenues. The results suggest several options for meeting both the 30 and 50% objectives of the Ministry of Agriculture, but that in each case, certain large water-intensive crops must be substantially reduced or eliminated. Effectively, crop switching of this nature is likely to represent megatrends in Saudi Arabia in particular, and the Gulf countries in general, as this region tries to reduce water consumption while safeguarding food security. For each option, the water reductions lead to energy savings, with the amount of energy saved being a function of where the actual water reductions occur. The water savings lead to potentially large energy savings in instances where ground or surface water saved is used to displace desalinated water production, but any strategy to do this must consider potential effects on overall long-run water scarcity in the country.

We explored the potential implications of the different water reduction strategies on the agricultural sectors. The results suggest that palatable options exist, with the most likely option from a group negotiation being Scenario 7. This scenario resulted in a 47% decrease in water through eliminating fodder and wheat, significantly decreasing the production of grains, and increasing the production of dairy, fruit, meat and vegetables. This finding defies the notion that small water reductions would be more strategically palatable than larger ones. If water usage is to be minimised while maintaining gross revenue and production, then the primary candidates for reduction are those with large water intensity and low revenue and/or low production. Eliminating these types of crops would yield higher water savings than moderate reductions across a large portfolio of crops.

Future research will explore the role of input prices in the decision to produce certain crops. As discussed earlier, subsidies play an imperative role in Saudi Arabian agriculture sector. Policymakers effectively choose which crops and livestock are produced through the subsidies that are provided. When policymakers seek to increase the production of certain crops, or reduce the prices paid by consumers for domestically produced crops, subsidies for these crops are raised; and when certain domestic crops fall out of favour, as was the case with barley in the 1990s, and wheat more recently, subsidies are reduced, making them uneconomical for producers. Given this, it is the subsidy regime, and not market forces, that effectively determine quantities and prices of domestically produced agricultural products. A second-order assessment might be formulated as a mixed complementarity problem to and explore the role of input prices in crop production, and ultimately water consumption.

Although the FAO has provided a definition of food insecurity, there is no useful definition for food security at the national level. A definition should measure the risk of shortfalls in food supply, both domestically and internationally. One measure is the level of inventory until the next harvest, another is the risk of high costs in covering a domestic shortfall, and still another is the threat of an embargo. Capturing the uncertainty of supply involves modelling the uncertainty of outcomes. Potentially relevant approaches include the models developed in finance or grain storage (Gustafson 1958). Future work should examine what would be an appropriate representation of this uncertainty.

Finally, we offer a case study on the policy options for reducing water consumption while maintaining food security and farmer livelihoods in Saudi Arabia. This analysis, however, represents a broader megatrend that is increasingly relevant for many countries, particularly those that are water scarce. Given this, we encourage this methodology to be applied to other regions of the world so as to better understand the options and effects of managing this trade-off at a global level.

Acknowledgements The authors would like to thank Mathieu Carey and Berenice Garcia Tellez for their research assistance.

Appendix 1

Table 12.3 includes production values referenced from Saudi Arabia Ministry of Agriculture, Water Footprint data from (Multsch et al. 2013). Revenue data were extracted from the FAO's statistics database (FAO 2015). Data exceptions include Water footprint data for cabbages, eggs, fresh fruits, milk (cow, camel and goat), meat (camel, chicken cow, goat and sheep), honey, nuts, and pulses), which extracted from (Mekonnen and Hoekstra 2010).

Table 12.3 Data input for linear programming model

Crop	Initial production (tons)	Water footprint (m^3/ton)	Revenue (1000 US$/ton)
Alfalfa	2,659,449	2223	0.275
Barley	11,267	1544	0.119
Cabbages	7822	183	0.15
Carrots	56,121	427	0.249
Citrus	99,019	4281	0.452
Cucumbers	246,986	137	0.199
Dates	1,095,158	3059	0.511
Eggplants	59,023	634	0.214
Eggs	240,908	334	0.829
Fresh fruits	360,000	4753	0.349
Gourds	119,873	646	0.175
Grapes	134,484	1448	0.572
Honey	108	0	2.509
Maize	95,356	3556	0.142
Meat (camel)	22,552	427	2.096
Meat (chicken)	604,000	502	1.424
Meat (cow)	174,000	631	2.701
Meat (goat)	3334	276	2.396
Meat (sheep)	16,277	375	2.723
Melons	230,246	549	0.184
Milk (camel)	105,000	330	0.341
Milk (cow)	1,943,000	330	0.312
Milk (goat)	80,000	330	0.336
Milk (sheep)	68,000	594	0.389
Millet	4486	4848	0.181
Nuts (ground)	2050	1457	0.451
Okra	44,454	398	0.639
Onions	112,478	243	0.21
Other Fodder	1,318,090	1887	0.275
Potatoes	390,259	524	0.169
Pulses	14,000	3374	0.556
Sesame seeds	2487	6568	0.677
Sorghum	110,299	3420	0.154
Tomatoes	544,464	338	0.37
Vegetables	526,408	761	0.188
Watermelons	401,058	407	0.114
Wheat	660,145	2233	0.158

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Chapter 13
Nestlé and Its Response to Megatrends in Water

Paul Bulcke

Abstract Over the past 15 years, several water megatrends have accelerated and been accentuated, challenging societies and economies across the world. These include growing water shortages stemming from overuse, increasing risk of political and/or societal tensions around water access and use, heightened risks for the water supply security of private companies, and, last but not least, the deterioration of water infrastructure (municipal, other) due to insufficient investment. Water is not a new concern for Nestlé. From the very start of Nestlé's industrial activities, 150 years ago, water has been central to the company. Today, three concerns are at the forefront: will there be enough water to grow the food needed both to feed people directly and as an input for its production; will there be the necessary water security (supply and quality) for the operations of its factories; and, finally, will there be safe water for its consumers to prepare their meals? As these new megatrends were emerging, the company took a closer look at its overall water strategy. This resulted in a comprehensive water stewardship approach covering four strategic impact areas—factories, watersheds, agriculture supply chain and communities—and including collective action such as joining and setting up overarching alliances amongst stakeholders in local watersheds and providing support for the strategic approaches of governments to address water challenges, particularly overuse, in a relevant and cost-effective manner.

Keywords Water resources strategy · Creating shared value · Collective action
Social development · Corporate actions · Water stewardship

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13.1 A Look Back: Water as a Priority for Nestlé Since the Beginning; Evolving Discussion, Main Decisions and New Steps Taken in the Early Twenty-First Century

Water has been central to Nestlé from its' very beginnings. Figure 13.1 shows the very first Nestlé factory that was built right next to a river. On the occasion of the company's 150th anniversary, in June 2016, this site was re-opened as a visitor centre for the general public to discover Nestlé, describing its historic roots, as well as providing a vision into the future around the complex relationships between nutrition, health and wellness.

Until the 1990s, and in many cases subsequently, all major factories of the Nestlé Group have been located next to water sources (rivers, canals, underground aquifers), typically within a water-rail-road triangle. Water matters for the company, even if its factories are not big water users.

Besides access and withdrawal, Nestlé's first wastewater treatment plant became operational as early as the 1930s. Right across the world today, we do not leave our wastewater untreated, even where conditions make this difficult. An example of this is the wastewater treatment plant set up in the early 1990s in one of our factories in northern China that needs heating due to the often very cold climate. Indeed, Nestlé's comprehensive view of, and sense of responsibility for, water is not just a recent phenomenon but is one that is well-rooted in the company's history and culture and one that has deepened further throughout its 150 years of existence.

The first acquisition of a bottled water company in the 1970s added a new dimension to Nestlé's approach. Steps to protect the quality of groundwater became an integral part of the Nestlé philosophy. One example of this is Agrivair, an initiative set up at the end of the 1980s in cooperation with the local farming community (including paying those farmers who reduced their use of pesticides, artificial fertilisers and manure for their 'environmental services') to protect the entire water catchment area in and around Vittel (Institut National de la Recherche Agronomique 2006).

At the beginning of the twenty-first century, it became clear that the world of water and the world around water were undergoing quicker and more profound changes than ever. At a Nestlé executive board strategy retreat in Glion, Switzerland, on 5 November 2002, a discussion on the terms of reference for a new and broader corporate approach to water was initiated. Subsequently, Nestlé's then Chief Executive Officer (CEO) and subsequent Chairman, Peter Brabeck-Letmathe, defined water as the biggest long-term challenge for the existence of the company. Notwithstanding some initially differing views internally, Nestlé decided to take a pro-active and publicly visible role on water issues around the world. This has continued ever since.

In January 2005, at the World Economic Forum (WEF) Annual Meeting in Davos, Nestlé invited a group of experts, diverse enough to fully represent the complexity of the water issue (including soft issues like spirituality, emotions, etc.),

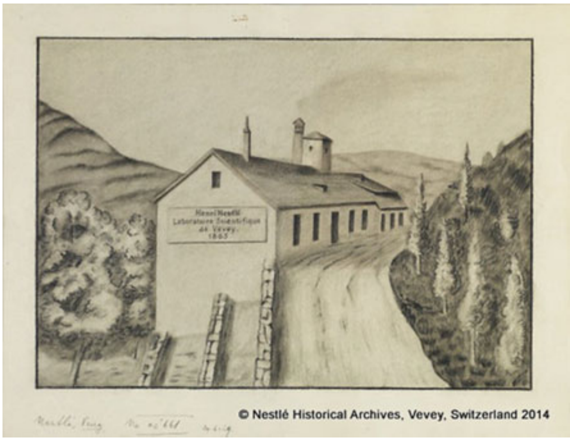

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Fig. 13.1 First Nestlé factory built next to a river

to further develop the factual base for our future strategy (Bravermann et al. 2005). It was also the first time that, on behalf of the company, Mr. Brabeck publicly subscribed to the concept of water as a human right (Brabeck-Letmathe 2005). Together with the strong support provided by Professor Klaus Schwab, Founder and Executive Chairman of the WEF, this Nestlé event put water firmly on the WEF agenda as a priority theme.

From there followed several phases of reflection and the identification of forward-looking steps to develop and build Nestlé's position and to take actions to meet the water challenges. Among the main actions were the following:

- In 2007, Nestlé joined the UN Global Compact CEO Water Mandate, designed to assist companies in the development, implementation, and disclosure of corporate water stewardship practices and policies.
- In 2008, water became one of the three pillars of Creating Shared Value (CSV),[1] Nestlé's fundamental guiding principle to how Nestlé does business responsibly.
- In 2008, a small group of manufacturers together with the International Finance Corporation (IFC) of the World Bank Group and McKinsey established the 2030 Water Resources Group (WRG) as an ad hoc platform to tackle the challenge of water overuse. In November 2009, the WRG published 'Charting Our Water Future', which put watersheds at the centre of the analysis and proposed tools to stimulate cost-effective and relevant action for policymakers and stakeholders (2030 WRG 2009). Based on the conclusions of the report, Nestlé and other WRG members expressed reservations on the concept of water

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[1] Definition of 'Creating Shared Value': We believe we can make an important contribution to society, by going a step beyond corporate social responsibility to create value through our core business both for our shareholders and society. We prioritise the areas of nutrition, water and rural development to create shared value; this requires long-term thinking.

neutrality for specific actors and the use of ‘water footprints’ as effective policy drivers and key policy performance indicators.

- In January 2010, the 2030 WRG was formalised, initially hosted within the WEF, and then, from 2012, within the World Bank Group. Nestlé’s then Chairman, Mr. Brabeck, chaired the WRG Governing Council until mid-2017 (IFC 2011) and, I, in my capacity as Chairman of Nestlé since April 2017, have recently taken over the position of Co-Chair alongside a senior representative from the World Bank Group.
- In 2011, Nestlé received the Stockholm Industry Water Award for its management practices for water (Stockholm International Water Institute 2011).
- In 2012, the first CSV report with a focus on water—Meeting the Global Water Challenge—was published as part of Nestlé’s 2011 Annual Report. This further refined the systematic measurement of water use and disposal by the company (Nestlé Public Affairs 2012).
- In 2014–2015, Nestlé’s then Chairman, Mr. Brabeck, participated in the work of the High Level Panel on Financing Infrastructure for a Water-Secure World (World Water Council 2015). This is just one example of Mr. Brabeck’s active involvement in broad public policy discussions on water on a global scale. Another example was his role as the private sector ‘water ambassador’ for the UN Eminent Persons Group tasked with setting the 2015 UN Sustainable Development Goals (SDGs). In this process, and together with others, Nestlé strongly and successfully advocated for water to become a stand-alone goal within the SDGs, with clear and specific targets, including a specific target devoted ‘to bringing freshwater withdrawals back into line with sustainable supply’ (Brabeck-Letmathe 2014).
- In 2015, following the WEF Africa Summit in Cape Town in June, Mr. Brabeck joined in campaigning for the G77 Urban Water Alliance proposed by the South African government (Brabeck-Letmathe 2015).
- In 2017, Nestlé launched its guidelines on the human right to water, which commit the company to respect the do-no-harm principle.

Alongside these actions, at the highest level of the company, many Nestlé colleagues at headquarters and across the world have embraced the water challenge agenda and been actively and deeply involved in water-related discussions and initiatives such as Caring for Water. The initiative, relayed in markets through local water plans, builds upon existing water efficiency interventions in factories and sets an emphasis on water stewardship activities outside the factory walls, meaning in watersheds, in the agricultural supply chain and in communities.

13.2 Scenarios 2030: A Global/General View on Some Major Water Megatrends and Challenges

Let me outline some of the major trends, interrelated and, at times, re-enforcing that may become more relevant as we move towards the year 2030 and beyond.

First and foremost, there is a growing water use/overuse challenge, resulting in increasing shortages. For the year 2015, estimates by the 2030 WRG suggest that withdrawals exceeded sustainable supply (natural renewal minus environmental flows and needs) by close to 20%, i.e. a deficit of 800 km^3. Scenarios for 2030 show that this gap could increase to 2700 km^3, i.e. withdrawals that are more than 40% in excess of sustainable supply. Often this overuse is visible (drying rivers, e.g. the Aral Sea being transformed into a sand desert); more often it is not, reflected rather in water tables of underground aquifers in both developed and developing countries sinking at an alarming rate (Parker 2016a). As the former Chairman of Nestlé has said on several occasions (including when the oil price was much higher than today): 'we will run out of clean water long before we run out of oil'.

With growing overuse comes increasing imbalances in the exposure of countries to water risks from such unsustainable practices. As water is local, problems will not emerge in all countries simultaneously. People may therefore have difficulties to understand and estimate reliably the global nature and repercussions of the current developments. Fragmented availability of data and transparency and, in some cases, even absence of national water accounting (including, but not exclusively, in cross-border river basins) will further exacerbate the risks.

As water is key for individual life and for societies, the political dimension of these trends is particularly delicate. We are already witnessing increasing water conflicts, particularly within countries, between various water users. Unless there are major changes in water management practices, the situation is likely to worsen further.

Companies may be held responsible or at least accountable (Scientific American 2014) for the overuse, pollution and other water-related issues far beyond their operations and their areas of influence. These and other factors combined may lead to an increased risk of arbitrary re-allocation of water which may not be justifiable or equitable (Parker 2016b).

In parallel, there is a widening investment gap in common water infrastructure, (public water supply, wastewater collection and treatment) including in advanced economies, with an order of magnitude of up to 50% of actual needs. This leads to the erosion of both the quality and quantity of municipal water that actually reaches consumers (OECD 2006).

13.3 Areas of Concern

Global food supply risks are being affected in a very significant manner by water overuse. If no measures are taken, the world may face shortfalls due to water security in the order of 30% in cereal production by 2030 and, in particular, may risk the overuse of buffers (groundwater and lakes that are in excess of renewal) that should be protected for use in times of droughts (2030 WRG 2009).

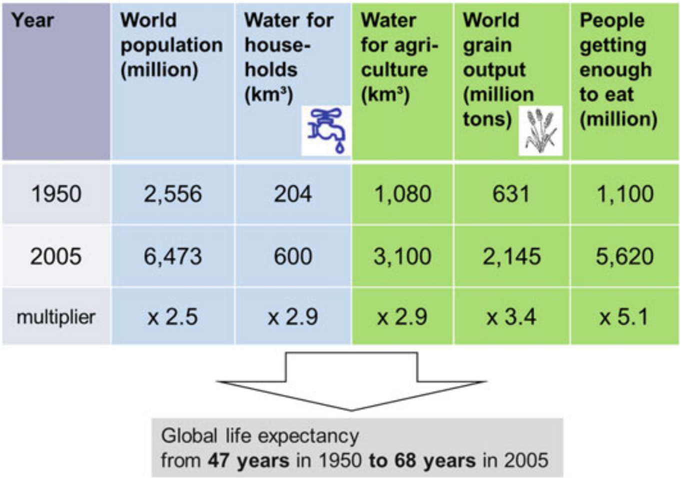
From a broader vantage point, water may no longer act as a driving force behind societal prosperity and economic growth as we have seen in the past. This may significantly affect the operations of companies like Nestlé in water scarce regions.

To illustrate the risks from water scarcity for broader wellbeing, let me describe the reverse picture. Until now, increasing water availability (when and where needed) and increased withdrawals have been an integral part of development process and societal progress.

Figure 13.2 shows the strong positive impact that water has had on societal prosperity since 1950.

Between 1950 and 2005, world grain output increased at a much higher rate than world population, driven by increased water withdrawals, and also greater water efficiency. Improvements in the supply of safe water for households were one of the major drivers of the increase in life expectancy from an average of some 45 years in 1950 to more than 65 years in 2005 (Fig. 13.2).

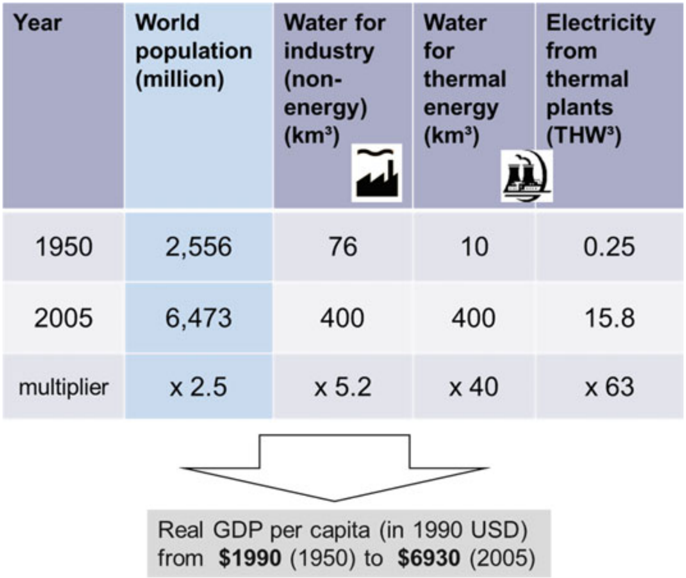
For a company like Nestlé, it is of strategic and existential importance that this positive process continues.



Year	World population (million)	Water for house-holds (km^3)	Water for agri-culture (km^3)	World grain output (million tons)	People getting enough to eat (million)
1950	2,556	204	1,080	631	1,100
2005	6,473	600	3,100	2,145	5,620
multiplier	x 2.5	x 2.9	x 2.9	x 3.4	x 5.1

Global life expectancy
from **47 years** in 1950 **to 68 years** in 2005

Fig. 13.2 Mobilising water for social development, 1950–2005. *Source* IEA (1999)



Year	World population (million)	Water for industry (non-energy) (km^3)	Water for thermal energy (km^3)	Electricity from thermal plants (THW^3)
1950	2,556	76	10	0.25
2005	6,473	400	400	15.8
multiplier	x 2.5	x 5.2	x 40	x 63

Real GDP per capita (in 1990 USD)
from **\$1990** (1950) to **\$6930** (2005)

Fig. 13.3 Mobilising Water for Economic Growth, 1950–2005. *Source* IEA ((1999))

At the same time, water matters for economic growth driven by industry.

We need water for our operations. As for many other sectors of industry, freshwater availability and efficiency of its use must continue to be able to act as drivers of economic prosperity.

Nestlé is, given its less than 1.5 litres of freshwater withdrawals per US$ of sales, a very small user, but water is essential for a number of processes.

Indeed, companies from diverse sectors must also consider the indirect impact of water availability, that is, water availability for functions that are not directly linked to their operations. A particularly important example of this is illustrated by the fact that more than half of the water withdrawn for industry is used for the generation of thermal power. Fresh water is also needed for the generation of solar power (Carter and Campbell 2009) (Fig. 13.3).

As water scarcity increasingly becomes a reality in most parts of the world, there is an urgent need for better management practices and processes. This should probably start with the proper valuing of water and comprehensive water accounting/monitoring (withdrawal/use/return flows/quality levels/etc.) together with tools for value-maximisation of available water resources (societal value, utility, etc.). This has been a long-term demand of the proponents of Integrated Water Resources Management (IWRM).[2]

13.4 Addressing the Challenges from Water Megatrends

Water-related megatrends need a corporate response and, in the context of the Caring for Water Initiative referenced above, Nestlé has identified four strategic impact areas: factories, watersheds, agriculture supply chain and communities. Each impact area is necessary but not sufficient, i.e. each needs to be understood and developed in the context of the others.

We must look for ways to mitigate the direct risks to the company emanating from water shortages and quality failures and to protect our operations at relevant levels (factories, administration, sales, etc.). One way this can be done is by steadily reducing water requirements and extending wastewater treatment (quantity and quality) as well as reuse.

We must commit to strategically act and invest in resources outside our factories, through collective action. In this perspective, we can advocate and, importantly, help develop, collectively, comprehensive solutions within watersheds and countries through coherent and credible government-led multi-stakeholder action. This commitment must be made within a global perspective—i.e., not just in those countries and river basins where we operate—because of the generalised risk of global food shortage from water overuse/shortfalls. This also includes participation in the public policy dialogue both at the international and local levels.

While focus is given to our operations, this may, at least partly, be extended to the agriculture supply chain, to make it more resilient (see Sect. 13.4.1). The agricultural sector is a large user of water. We need to look to contribute to improvements in water resource management in the agricultural supply chain to ensure that, collectively, we become more efficient.

Finally we must also invest in communities, certainly in terms of the activities of our operations and the immediate communities surrounding these, including rural communities, but also along our entire value chain, because healthy communities are the basis of economic development. We must put a particular focus on the agricultural sector as a large user of water, and look to contribute to improvements in water resource management in the agricultural supply chain to ensure that, collectively, we become more efficient.

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[2] IWRM is hence a ‘process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems.’ Global Water Partnership (2004).

13.4.1 Some Key Corporate Initiatives and Projects

Let me illustrate a few examples of concrete action taken by Nestlé:

- In line with our commitment, Nestlé has actively sought, and will continue to seek, new opportunities to reduce, reuse and recycle water in our operations. Water withdrawals per tonne of product have been reduced by 39% between 2006 and 2016. Our local master plans in key markets contain documented responsibilities, targets and deadlines that will drive further improvements. Today, Nestlé is delivering over 516 water-saving projects in Nestlé's factories, intending to save around 3.7 million m^3 of water a year. Our achievements include the first zero water technology project implemented at a factory located in the central, water-stressed state of Jalisco in Mexico. We have similar plans for facilities in South Africa, India, Pakistan, China, the Philippines, Brazil and California. In 2016 alone, we reduced direct water withdrawals per tonne of product by 4%. We have set ourselves a new, stretching 10-year target for 2020 with a 2010 baseline. It is worth noting that, as we make our processes more efficient, it becomes increasingly more challenging to improve at the same rate. Nevertheless, our target is a 35% reduction per tonne of product.
- We have identified and prioritised 24 high-priority manufacturing facilities that are located in areas of severe water stress and/or represent a significant portion of our water withdrawals. By the end of 2016, we have decreased water withdrawals and improved efficiency (against 2013 levels) in 21 of these facilities, saving 1.8 million m^3 of water. These are, from my perspective, good examples of CSV. By reducing water intake, we provide value for society and, by reducing risk, we provide value for our shareholders.
- Water, Sanitation and Hygiene (WASH) considerations are being integrated into the process. We continue to work with expert partners, including the World Business Council for Sustainable Development (WBCSD) and the International Federation of Red Cross and Red Crescent Societies (IFRC) to improve access to water and sanitation. In 2016, we implemented the WBCSD self-assessment WASH tool at key manufacturing sites and were able to confirm that more than 500,000 people had access to water, sanitation or hygiene around our manufacturing facilities and in Farmer Connect areas, thus surpassing our 2016 target (350,000).
- The huge amount of food lost or wasted globally contributes significantly to water overuse. In 2016, in my capacity as CEO, I joined Champions 12.3, a coalition of government, industry and NGO influencers dedicated to accelerating progress towards halving food waste by 2030. Also, as Nestlé, we have guided the Consumer Goods Forum to adopt the public resolution of halving food waste from its members own operations by 2025, five years ahead of UN SDG number 12.3.
- Through education initiatives, we are helping our employees, suppliers and consumers improve their understanding of the importance of water conservation and stewardship. In addition to supplier activities, we have continued our

sponsorship of the global water education programme, ‘Project WET’, also in countries such as Nigeria.

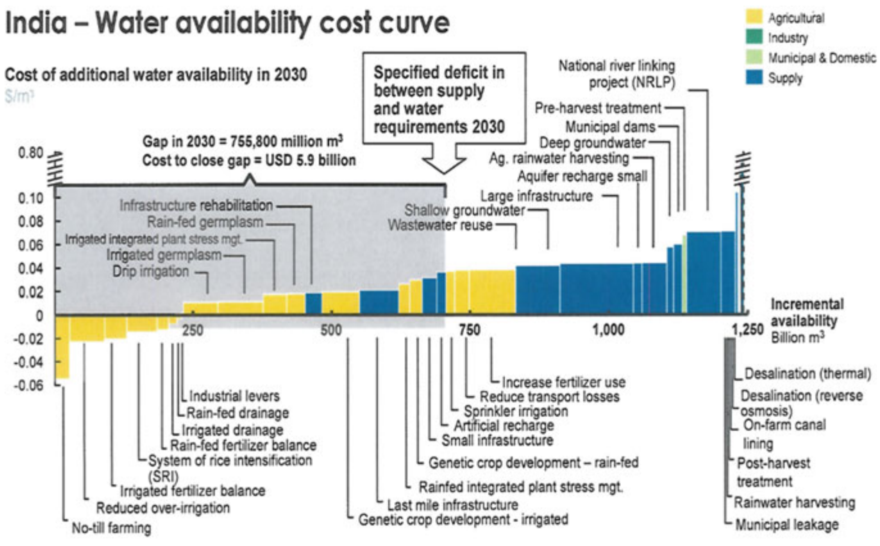
Let me inject one word of caution at this point. Since food manufacturing, and Nestlé in particular, are relatively small water users, the impact of our actions on the overall water situation must not be overstated. We must caution against exaggerated expectations by society as to what Nestlé alone can achieve, even if our actions remain important in terms of, for example, risk reduction or demonstration of good corporate practice. In some circumstances, it may be that the most cost-effective actions within a watershed are those that need to be taken by other actors (2030 WRG 2009).

13.4.2 Comprehensive Action: 2030 Water Resources Group

As I have noted, there is a crucial need for a broader perspective, i.e. initiatives to contribute to comprehensive and credible and often disruptive solutions (in the sense of Schumpeter and Christensen) to overcome water overuse. The most important initiative for us in this respect is the 2030 WRG that Nestlé has been chairing since its creation (Fig. 13.4).

The 2030 WRG starts from the premise that government is the ultimate custodian of water and is essential for comprehensive strategies in watersheds. The 2015 UN SDG on Water and the High Level Panel on Water announced at the 2016 Annual Meeting of the WEF (Brabeck-Letmathe 2016) provides a framework to deliver the six targets of the Water Goal in individual countries, breaking down silos at the highest level, building on existing partnerships and initiatives to bring efforts to scale and transforming the water agenda, in cooperation with the private sector and others.

Fig. 13.4 2030 WRG: donors and partners (https://www.2030wrg.org/who-we-are/partners/)



SOURCE: 2030 Water Resources Group

Fig. 13.5 India-water availability cost curve (2030 WRG (2009), Charting our Water Future)

The 2030 WRG is one of the partnerships that will step in. It provides the analytic tools for a relevant, cost-effective approach to improved water efficiency in areas with water overuse, helps with the convening of concerned stakeholders in a watershed, and supports, in some instance even drives, the necessary transformation. As it aims for comprehensive, credible local action, it also strives to overcome the 'tragedy of the commons' in watersheds.

One tool for this is the water availability cost curve; see Fig. 13.5 for the Indian case. This summarises the status of the country's 19 major river basins and underground aquifers with an eye on the deficit between water supply and requirements in 2030.

This tool helps guide governments and stakeholder groups towards those measures that will deliver the highest return per invested dollar (the levers situated on the left-hand side of the chart), and it helps avoid 'make-believe' actions that do not contribute a significant amount to closing the actual water gap (measured as the distance on the *x*-axis).

Water issues are always local. In the approach proposed by the 2030 WRG, therefore, action is driven by local stakeholder groups, under the leadership of governments. Strategies build on a growing set of locally driven initiatives and programmes with the ambition to ultimately impact the global situation.

In a world characterised by scenarios featuring increasing numbers of occurrences of water overuse/shortage, themselves triggering a global food crisis (possibly by 2025 or 2030), it is clearly in the interest of Nestlé that the 2030 WRG also works in regions where we do not have a direct supply chain. Indeed, the indirect impact of turmoil resulting from a significant global food crisis would affect the company beyond its supply links.

The 2030 WRG works with a lean and global institutional structure, even if it is local action and priority-setting that matters, and its Secretariat is embedded in the World Bank Groups. Indeed, there are certain activities that may benefit from global structures and networks, such as developing catalogues of good practice to exchange and disseminate learnings discovered in individual countries/watersheds (2030 WRG 2012, 2013).

13.4.3 Outlook on Possible Further Concrete Action—At Company Level and in Partnership

As I believe I have emphasised, the challenges relating to water are significant, but so is the potential for solutions. First and foremost, existing technologies and well-proven best practices should be implemented much more broadly. But there are also opportunities beyond what is already known and/or being done.

Let me just give very few examples of what should and could be done at many different levels.

At Nestlé, we are making considerable efforts to have zero water waste operations in our factories (e.g. to reuse the water already being used) and, where we can, waste reduction in our value chain. This is highly relevant also to address water overuse, thus reducing the waste of embedded water. We can also contribute to implement aspects of a circular economy, e.g. with bio-digesters for farmers.

We may help in initiating better watershed management, e.g. based on the experience of source catchment protection set up by Nestlé Waters. Here, and in other projects, there may well be potential for innovative technologies.

This article also emphasises the importance of the 2030 WRG as part of the overall strategy. The 2030 WRG activities have moved beyond a pilot phase, but are still limited in their outreach. There is, therefore, a need for deepening and widening these, extending its reach to more countries, including if possible to advanced economies.

Within the 2030 WRG, and beyond, there is no doubt potential for further research and for the use of new technologies in devising solutions, particularly in the sphere of wastewater, but also, e.g. harnessing big data to drive greater efficiency in agricultural water use and looking into the potential of zero-water farming.

Underlying all the above, it remains essential to increase awareness of the water challenge across all segments of the population and to intensify the public policy dialogue on water, involving those directly concerned by today's water megatrends.

13.5 Bringing Together of Megatrends in Water, Concerns and Responses

In closing, here is a summary bringing together the major challenges in the water space, the concerns for a company such as Nestlé and the different levels of action.

Global megatrends in water are a challenge for societies and economies, including:

- Overuse and poor water management, which create and exacerbate water shortages;
- Increased political and/or societal tensions, driven by water scarcity;
- Deterioration of water infrastructure (municipal or other).

There are three major areas of concern for Nestle:

- Water is essential for farmers from whom Nestlé sources its raw materials to add value for consumers;
- Water matters for the company's factories to operate; it must also be available for the daily needs of its workers and their families;
- Safe water is a requirement for the consumers of many, if not most, Nestlé products, i.e. to prepare meals and ensure basic hygiene in the kitchen and beyond; consumers moreover expect safe and high-quality water for healthy hydration.

Nestlé sees a comprehensive action strategy in response:

- Reducing our water withdrawals and use and finding new ways of reusing water to ensure that nothing is wasted, both within our operations but also across those we work with in our supply chain, including agriculture;
- Participating in alliances for comprehensive solutions at the country and watershed levels. A key partnership for us is the 2030 WRG, which seeks to address and redress water overuse/management and other issues in specific watersheds in a relevant and cost-effective manner;
- Working with all parts of the communities around our operations and our supply chain, notably agriculture, to further the understanding of how to take care of available water.

The strategy has a long-term perspective, but the time for action is now!

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