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Chapter 1
Ensuring Water Security Under Climate Change

Asit K. Biswas and Cecilia Tortajada

Abstract Water security and climate change are only two of the major long-term problems the world is facing at present. Increasing population, urbanisation and demands for a better quality of life all over the world mean more food, energy and other resources will be necessary in the future. Increasing food and energy supplies will require more efficient water management all over the production and supply chains. All these requirements have to be met in a way so that significantly less greenhouse gasses are emitted into the atmosphere which are contributing to climate change at an increasing scale. Historically, the total global water demands have steadily increased. Currently, about 70% of global water is used by agriculture, 20% by industry and 10% by domestic. In all these three use areas, there is enough knowledge available to reduce water requirements very significantly. Agricultural production can be very substantially increased with much-lower water requirements. Domestic and industrial wastewaters can be collected, treated and reused. With proper management, this virtuous cycle can be a reality. While conceptually global water security can be assured by using current knowledge, climate change considerations have made ensuring global water security a very complex task. This is because major uncertainties are associated with any forecast of future extreme rainfalls and then translating them into runoffs in river basins and sub-basins which often are units of planning. This chapter reviews and assesses what can be done to ensure water security for individual countries as well as the world as a whole. Thereafter it analyses the risks and uncertainties that policymakers and water professionals are likely to face in dealing with climate change through the lens of water security.

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1.1 Introduction

Water security and climate change are only two of the major problems humankind is facing at present. These two issues will continue to be serious global problems for decades to come because most of the issues that are associated with them will continue to change over time and space. Important though these two long-term problems are, there are also many other serious problems that the world is facing at present. Probably an important first-order problem is the steady increase in the global population. The current global population of around 7.85 billion is likely to increase to 9.7 billion by 2050, and 11 billion by 2100 (UN Population Division 2019a). In 2019, 55.7% of the population lived in urban areas, and this percentage figure is estimated to increase to 68% by 2050, and then further to 85% by 2100 (UN Population Division 2019b). This means an increasingly larger percentage of global population is likely to be concentrated in and around urban centres. This will put increasing and serious stress in and around these areas in terms of reliable provision of every type of major human needs like food, energy, water, other natural resources, environment, public health, medical and all other forms of social services, housing, land use, transportation and numerous other associated issues.

In addition, in the coming years, there will be considerable emphasis on poverty alleviation focusing on increasing standards of living of all people, industrialisation, all forms of social requirements, including employment generation, better and more efficient connectivities and a better environment (Biswas 2021).

All these major issues facing the world are interrelated. The dynamics of the future of humankind will be determined not by any one or two issues, but by the interactions and impacts of a multitude of them. For example, increasing population and demand for steadily improving standard and quality of life will mean that more food, energy and other materials will be required, unless there are major changes in efficiencies in terms of how they are produced and used. Augmenting and ensuring appropriate food and energy supplies will necessitate sustainable and increasingly more efficient water management in their production, supply and use. Equally, many of these developments may mean, unless special measures are taken, more greenhouse gases may be emitted into the atmosphere which could contribute to global warming and result in climate change through numerous pathways, some known and identifiable at present, but others not known or fully appreciated. This may further precipitate a host of additional second-order problems which could seriously affect existing food production and supply arrangements, energy requirements and use patterns as well as water management practices and processes.

In the coming years it will be important to ensure that the solutions that are deemed to be effective to solve one major problem do not create problems in other areas and/or regions. This has often been a recurring problem in the past: solutions to solve one problem have mostly created serious problems in other areas. Accordingly, it is essential that solutions be sought after considering and assessing the overall problematique rather than focusing exclusively on solution of any one specific individual problem. Taking such a holistic analytical and assessing framework is becoming an increasingly complex and difficult task, technically, institutionally and nationally.

Climate change is already having serious impacts on the world. Figure 1.1 shows estimated economic losses due to climate-related disasters as a percentage of GDP for countries at different income levels, during the period 1998–2007. It categorically shows that economic losses as a percentage of GDPs were much higher for low-income countries compared to high-income countries, by nearly a factor of 4.5. This means low-income countries not only face much higher and widespread losses but also, they have less funds, management and administrative expertise, lower access to adaptation and use of technology and inadequate institutional capacities. These constraints are unlikely to change markedly in the future. Accordingly, economic losses from climate-related costs are highly likely to increase significantly in the low-income countries. This may further exacerbate inequalities between rich and poor countries, as well as between rich and the poor in the low income and lower middle-income countries. This would aggravate already serious situations even more even further.

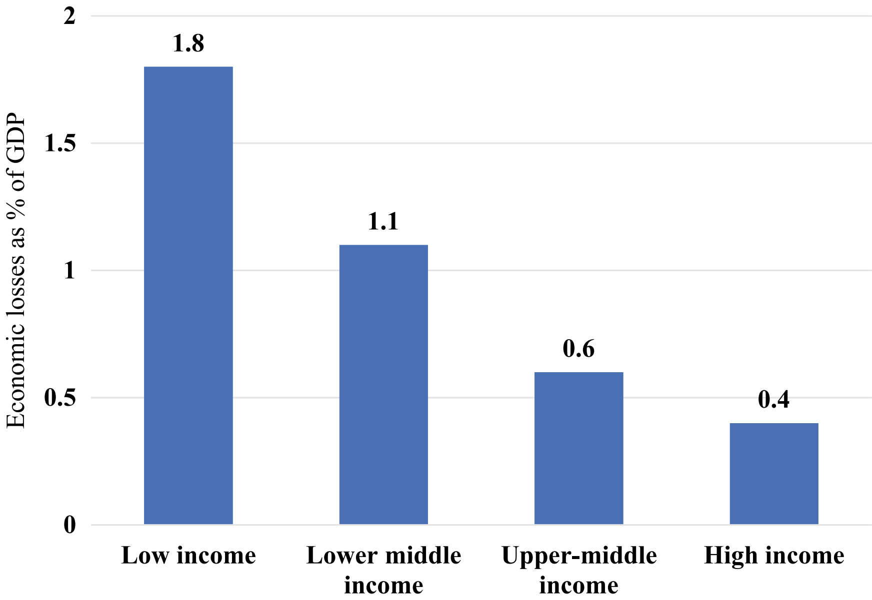

Fig. 1.1 Economic losses due climate-related disasters as % of GDP, 1998–2007. *Source* Adapted from Wallemacq and House (2018)

1.2 Water Security

The Ministerial Declaration during the Second World Water Forum held in The Hague, in March 2000, defined water security as "ensuring freshwater, coastal and related ecosystems are protected and improved, that sustainable development and political stability are improved, that every person has access to enough safe water at an affordable cost to lead a healthy and productive life, and that vulnerable population are protected from the risks of water-related hazards."

While there are numerous other definitions of water security, the overall context of all of them is somewhat similar. They all, directly or indirectly, refer to the fact that water security means everyone has reliable and ready access to adequate quantity and proper quality of water, and enough water is available on a reliable and timely basis for all social and economic needs, proper water quality is maintained, and people are protected from water-related disasters.

While conceptually it may be relatively easy to agree on a definition of water security at national or subnational levels, the problems associated with assuring water security for a specific region or nation are inordinately complex. In addition, it is difficult to formulate policies addressing all components of water security, let alone implement them properly on a timely basis. Difficulties are further compounded because different parts of the water security landscape invariably change over space and time. Additionally, societal attitudes and perceptions of the various factors that contribute to water security are continually evolving. Thus, on an operational level, it has been exceedingly difficult to formulate policies to assure water security, let alone implement them.

There are many factors which, in the final analysis, contribute to define water security. They cover many issues, including extent and structure of population growth; rate and extent of urbanisation; climate, soil and land use characteristics; institutional and governance capacities of institutions involved; level of sustained political interest in water; economic and behavioural aspects of how water is managed and used and people's attitudes to and perceptions of different water-related issues; technological advances and their adoption rates, as well as a host of other factors. Water security is ultimately the net result of all these interacting and often interrelated or even conflicting issues. These complexities and the fact that historically senior policymakers in almost all countries seldom have water as a priority item over the long-term in their political agendas, have ensured that water security has been hard to achieve in nearly all countries (Biswas and Tortajada 2019). The only major exception has been Singapore.

Historically there have been three main types of water uses all over the world. These are for domestic, industrial and agricultural purposes. Water allocation for environmental purposes has been a relative newcomer during the past 3–4 decades. It is becoming an increasingly important issue, but, as yet, very few countries have allocated water for environmental uses. If water security is to be assured for any country, the demands for all these four types of water requirements have to be met over the long-term in all countries.

In this chapter, the complexities of assessing demands to ensure water securities for the main three historical uses will be briefly considered, especially as environment has not been allocated in any specific quantum of water in most countries.

1.2.1 Water Security for Domestic Sector

Since human survival depends on adequate availability of water for domestic uses, it is undoubtedly the most important socio-political consideration in all countries. The Holy Quran explicitly stipulates that the humans should have first priority among water uses. It should also be noted that on 28 July 2010, United Nations General Assembly explicitly recognised the human right to water and sanitation and opined that clean drinking water is essential for the realisation of all other human rights. The resolution, however, does not address the industrial and agricultural uses of water, except in passing (Brooks 2008).

Complexities of ensuring water security can be realised by considering only a few essential issues embedded in its definition noted earlier. For example, what is exactly meant by "adequate quantity and quality" of water needed for an individual to lead a healthy and productive life? At a first glance, this may appear to be a rather simple and straightforward question to which most people have not given much serious thought or attention. This issue, in reality, is rather complicated and difficult to answer meaningfully.

Empirical studies available at present unambiguously indicate that the quantity of water used has important bearing on human health and well-being. However, there are no simple answers to the simple question like what is the daily water requirement of a human being to lead a healthy and productive life? Even the water needs for basic human survival is not easy to define. It depends on numerous factors, including body size, climate, type of work done by individuals, as well as their socio-cultural backgrounds and lifestyles.

Normally, the basic survival water requirement per person is around four litres per day. However, survival needs are very different from the water needed for leading a healthy and productive life. Unfortunately, very limited actual studies have been conducted on what are the daily water needs for human beings to lead a healthy life.

To our knowledge, only one global study is available at present on this important and fundamental question. Even this particular study was carried out over half a century ago, in Singapore, from 1960 to 1970. It attempted to correlate the quantity of water used in relation to incidences of waterborne diseases reported in all the Singaporean hospitals. Not surprisingly, it concluded that as domestic water use went up, disease incidents went down. However, there did not seem to be any noticeable improvement in health conditions beyond 75 L of water use per capita per day (lpcd). Hence, it may be concluded that this quantity represented a minimum level, at least for the Singaporean conditions at that time (Biswas 1981). Any additional water uses beyond 75 lpcd were found not to produce any perceptible health benefits: they were primarily of aesthetic nature and the result of personal preferences or convenience.

Unfortunately, similar studies have not been conducted in other parts of the world, especially in recent years, so that appropriate conclusions can be drawn. Without such definitive knowledge, it is very difficult to estimate what should be the per capita daily use that should be used in terms of estimating water security for the domestic sector for a city or a nation.

Some current data and trends indicate that the Singaporean results of around 75 L of water use per capita per day may be valid in other parts of the world even now. Assessments of the latest information available on per capita daily water use from various European cities indicate that perhaps 70–80 L may be adequate for a person to lead a healthy and productive life. Several Belgian urban centres have managed to bring their current daily per capita water consumption within the 70–80 L range. These levels for water use do not seem to have any adverse health impacts on their inhabitants. Spanish cities like Barcelona, Zaragoza, Valencia, Seville and Murcia have witnessed a steady decline in per capita daily use from around the year 2000 (Sauri 2019). For these cities, it is now less than 100 L at present. Current information from these cities is still show declining trends in per capita daily water use. Tallinn's water use is now below 90 lpcd.

The regulator of water for England and Wales, Ofwat, has already indicated that all the water utilities should try to reduce the per capita water consumption, by 2050, to half of what it was in 2020, which was 141 L. This means the average per capita daily water consumption should be around 70–71 lpcd by 2050, a figure that is similar to the level that was found in Singapore some five decades ago.

Not surprisingly, global trends in per capita water use are not uniform. For most countries, the general trend in per capita water use in recent years has been downward. This includes countries like the United States, Australia, Japan, all European countries and Singapore. The extent of the decline often varies from one country to another, and also from one city to another even in the same country. However, this decline is not a universal trend. Per capita water use in some countries and cities of the world has been increasing, like in Qatar and Phnom Penh, Cambodia (Biswas et al. 2021). Per capita water consumption during the past five years in Qatar has increased steadily. It is at present 590 lpcd for an average Qatari national. This is probably one of the highest domestic daily water consumption rates in any urban centre of the world.

Per capita water consumption is only one of the considerations for the domestic sector for assessing domestic water security. Equally important is the amount of water that is lost from the water utilities due to leakages, burst pipes, unauthorised connections and for other reasons which cannot be accounted for. Such losses are often quite high. In many countries, ranging from India, Mexico, Nigeria and Sri Lanka, losses of over 50% in many of their cities are not exactly uncommon. In a significant number of cities of the developing world, and even desert countries of the Middle East where water is in short supply, unaccounted for water losses of 35% or more are fairly common.

Even in highly developed countries like the United States and Canada a comprehensive study of water main break rates, indicated that they increased by 26% between 2012 and 2018 (Folkman 2018). For cast iron and asbestos cement pipes, which represent around 41% of installed water mains in these two countries, breakage rates increased by more than 40% over this 6-year period (Kolman 2018). In the world's most economically and technologically advanced country, the United States, well over eight billion litres of water are being lost each year. This represents about 14–18% of all water treated.

Thames Water, has been one of the very few water utilities that is completely in private hands for well over four decades and the largest water utility of England and Wales, was fined £120 million in 2018 by Ofwat, the water regulator, to compensate customers for consistent poor management of leaks. Privatised water utilities of England and Wales are losing through leakages some 3170 million litres per day, accounting to nearly 21% of their total production (PwC 2019). Progress in leakage reduction in England and Wales, for a variety of reasons, has basically stalled during the past two decades (Fig. 1.2).

Thus, a fundamental question that neither the policymakers nor the water profession has generally not asked, let alone answered, is should future water security assessments automatically accept these types of very significant losses, or should future estimates consider much lower levels of losses that can be achieved using present knowledge, technology and management practices? For example, a city like Tokyo now loses only 3.9% of its water, one of the very best performances in the world. In Singapore, the losses are around 5%. Whether future water security assessments consider 50, 20 or 5% losses for domestic water use sector, the resource requirements would be radically different.

The issues that water professionals and policymakers need to answer are should water security assessments consider that an average citizen should have access to 70–80 lpcd, as is now the case in many urban centres of Europe, or consider only incremental improvements in the coming years of their current per capita water use rates for estimating water security?

Depending upon what is decided, water requirements to ensure societal security will be very different. The efficient estimates may easily be only about 30–35% of

Fig. 1.2 Historical leakage in England and Wales. *Source* PwC 2019

using business-as-usual scenarios. It is not only in the domestic water use sector where there are major uncertainties in terms of assessing water security but also in the two other major water use sectors as well.

1.2.2 Water Security for Industrial Sector

Uncertainties associated with estimating water requirements for the domestic sector are also similar for the industrial sector. There are many factors which ultimately will ensure water security for the industrial sector. Water requirements for the industrial sector can be very significantly reduced from their current situations by better management practices, adopting new and cost-effective technologies that are already available to improve manufacturing processes, and realisation of their CEOs that if their businesses are to survive and thrive, their individual perceptions of importance and relevance of water have to be radically revised. While there are indications that this has happened, or is happening for some companies, regrettably an overwhelming number of CEOs still do not appreciate the extent of water and climate risks that are currently embedded in their existing business models. While more and more corporations are becoming aware of the importance of water security for their businesses, unfortunately a very significant percentage of industries are still neither aware nor considering such risks seriously and regularly.

While, globally, the percentage shares of industrial water requirements have steadily increased in recent decades, water requirements per unit of industrial outputs for several companies, especially multinational ones, have been steadily declining in recent decades. All the current trends indicate that these trends are not only likely to continue to decrease significantly in the coming years but also more and more multinational as well as national companies will follow these trends in the future out of both necessity and reputational reasons. If this happens, and it is likely to happen, water security estimates for industry would radically decline steadily in the coming years.

Water and energy are two absolutely essential requirements for any industry, anywhere in the world, so that they can operate. They are also closely interlinked. Energy cannot be generated without water, and, equally, water cannot be produced and used without energy. Improving the efficiency of production and use of one will positively impact on the other.

While it is essential for industry to have water to function, water requirements to produce same industrial goods often vary very significantly, depending upon the companies that manufacture them, their geographical locations, processes uses and management practices. Those companies that are aware of the importance and value of water, and the increasing climate and water risks that are likely to affect their existing business models, mostly require much smaller quantities of water to manufacture the same products compared to other more profligate companies that may require 2–10 times more water for similar operations.

During the post-2000 period, CEOs of numerous multinational companies became aware of the risks to their future expansion plans, and even eventual survival, unless they became increasingly water-efficient in their manufacturing processes, raw materials procurement practices and explicitly consider water and climate-related risks. Those multinational and national companies that have become aware of the importance of water security and climate change for smooth functioning of their businesses have started to realise that for their own long-term survival and growth, they must consider a holistic and coordinated approach which should adequately consider the risks posed by these new emerging factors. Accordingly, they have started to steadily improve their efficiencies of use of all resources needed in their manufacturing processes, including water.

Processes associated with energy generation and all types of manufacturing invariably contribute to greenhouse gas emissions which ultimately affect the climate. Corporations use all types of natural resources and chemicals to manufacture different types of products. Improving the efficiencies of resource use is an important consideration, but this alone is unlikely to be enough. In the final analysis, it is essential for each industry to have a clear understanding and appreciation of the interlinkages and inter-relationships between energy, water, other resources, greenhouse gas emissions and climate change. Each industry needs to manage these intricate interrelationships in a continually improving holistic and strategic manner. Focusing on improving the efficiency of one specific resource, which may be the most important resource for that company, may not contribute to an optimal and economically and environmentally efficient solution for the long-term.

From early 2000, many major multinational companies started to consider their water use patterns and management practices within their manufacturing plants. They also have shown an increasing interest in water use practices of their supply chains. These sustained interests have resulted in significant water savings during their manufacturing processes as well as the water requirements for the raw materials they need to produce various products. The net result of all these types of improvements has meant that water security for the industrial sector is constantly evolving in positive ways. Thus, what may have been the water requirements of any specific industry to assure security in 2000, is likely to be significantly higher than what is required now, some two decades later. The current indications are these estimates are likely to be even less in 2030, compared to what they are now.

A company like Nestlé, one of the world's largest 100 companies, is a good example to illustrate the above point. It significantly reduced its direct water withdrawals in every product category between 2005 and 2013. It has successfully managed to reduce its overall water requirements per tonne of products manufactured during this period by 33.3% (Brabeck-Letmathe 2016). It has further reduced wastewater discharges per tonne of product manufactured by 60.1% between 2003 and 2013. It also reduced total discharges by 37.2%. In addition, Nestlé recycled or reused 6.7 million m^3 of water in 2013, further reducing its water footprints. These numbers, since then, have progressively become even better.

In 2010, Nestlé started a 3-year study to measure consumptive use of water at farm levels. The company formulated a series of good practices for different crops needed for its factories in different parts of the world. It then proactively disseminated these findings to the farmers to improve their water use practices. Further, thousands of Nestlé agronomists worked with the farmers to improve their water use practices so that less water is used for farming. In addition, qualities of agricultural runoff were improved by ensuring efficient and timely use of fertilisers and pesticides (Biswas-Tortajada and Biswas 2015).

By investing continuously in technology and process development and improving management practices, Nestlé has continued to reduce its water requirements regularly and progressively. For example, between 2010 and 2020, it reduced direct water withdrawals per tonne of product in its manufacturing operations by 32%. In some countries like Spain, Nestlé has managed to reduce its water requirements per tonne of manufactured products by nearly 50% during the same period (Nestlé 2020).

There are many major industrial companies, both international and national, that have similarly reduced their water footprints since 2005, both in terms of quantity and quality, and are also practising circular economy in terms of water use. Nestlé is only one example. Other multinational companies with similar good water management records during the past 15 years include Unilever, Coca-Cola, Pepsi-Cola, Procter and Gamble, Nike, General Mills and Givaudan.

Generally, major industrial corporations are now increasingly adopting a 3-stage process for their water management.

During the first stage, companies are critically assessing all aspects of their current production processes to see where there are scopes for reducing water consumption. Second stage includes properly treating the wastewater produced in their factories so that it can be reused for different purposes within the factory walls. In the third stage, wherever and whenever possible, they are considering out-of-the-box unconventional techniques to extract water from the raw materials they use in their factories to manufacture products.

A good example of the third stage is Nestlé's effort to extract water from milk from their processing factories. Milk contains about 87% water. When it is heated to produce powdered or condensed milk, normally water in the milk is simply evaporated and then escapes into the atmosphere. However, when an appropriate shadow price for water is used, it makes very good economic sense to develop a process to catch the water vapour from milk processing and then condense it to produce water. This water is then properly treated to take out impurities like minerals and bacteria. Thereafter, this reclaimed water is used for water requirements of the plants.

Nestlé first tried this process in its milk factory in Lagos de Moreno, which is located in the arid region of north eastern of Jalisco, Mexico. This "zero-water" factory no longer needs to obtain water from local water sources. In 2018, which was a drought year, this factory even managed to sell extra reclaimed water to a nearby factory. After this success, Nestlé has similarly transformed some of its other milk factories in arid water scarce regions like Modesto, California; Mossel Bay, South Africa; and Qingdao, China. The plan is to transform its other milk processing factories located in water-scarce arid areas into zero-water factories.

Such innovative and unusual practices very significantly improve water security of the company over the long-term.

More and more similar out-of-the-box transformational practices are likely to occur in the future which would significantly reduce industry's water requirements, and contribute to improve their water security.

Major corporations have at least two important reasons to progressively improve their water management practices and processes, which could contribute to their water security requirements. First, they are becoming increasingly aware of the risks posed by not having reliable access to adequate quantities of water of acceptable qualities so that their suppliers can source the raw materials which their plants need to manufacture the necessary products, and then have enough water of right quality so that the products can be manufactured.

Second, good water management has become a reputational issue for major corporations. During the past decade, the way companies handle their economic, social and governance (ESG) issues has become an increasingly important factor for the investors. Shareholder activism to ensure that all major corporations follow good ESG practices have become an increasingly important consideration for them. Both the national and international media are increasingly assessing the ESG ratings of individual companies. Their stock prices may depend on their ESG performances, which was not an important consideration even a decade ago.

Both the reasons are likely to become progressively more important for corporations in the coming years. Thus, the senior-most company officials are likely to be forced to continually improve their resource use efficiencies, including for water, and reduce their greenhouse gas emissions significantly, in order that they could be considered to be good corporate entities. This will mean that their water and energy use practices will continue to become more and more efficient, quantities of wastewaters produced will become progressively lower, and reuse and recycling would progressively become normal practices. In addition, wastewaters are likely to be treated to higher degrees, and reused within the factory. All these developments would help industry to become progressively more water secure because their water requirements would become less and less in the future.

All these developments mean that water requirements for industrial purposes are likely to be significantly less for increasingly more major corporations during the second quarter of the twenty-first century, compared to the first quarter.

1.2.3 Water Use for Agricultural Sector

Agricultural water use is another area where the importance and relevance of current discussions on water security need to be reconsidered. At present, agriculture is the largest user of water, at around 70% of the total global use. In recent years, on a percentage basis, agriculture's share of total water use has been steadily declining. However, in terms of total quantity of water used, agriculture's water requirements are still increasing.

The fact remains that in nearly all countries similar, or even significantly more, quantities of agricultural products can be produced with substantially less quantities of water by better management practices and adoption of more efficient technological developments. Agricultural water use practices in most countries, including those in most developed ones, are inefficient, often significantly. Thus, considerable scope exists to decrease agricultural water requirements very substantially without affecting productivities or total production.

China is a good example. From about 2010, China has made significant improvements in agricultural water use management practices which have enabled it to increase its total agricultural production, but with steadily decreasing water use per hectare of irrigated land. Between 1990 and 2012, China's production of cereals increased by 35% and over 80% for cotton. During this 22-year period, the country's total agricultural water use increased only marginally, from 374 to 388 billion m^3 per year, an increase of around 4%. However, during this period water used per hectare of irrigated land declined by 22% (Doczi et al. 2014).

China's plans are to significantly increase agricultural production even further by 2030. However, this will be achieved with steadily decreasing water use per hectare of irrigated land. All practices and processes associated with water use and agricultural production would become increasingly more efficient through increasing investments, institutional modifications and strengthening and steadily adopting latest technological developments, including information technology, artificial intelligence and data analytics. Other countries can, and should, follow China's example and reduce their agricultural water use in the future very substantially. Such steps will substantially reduce water requirements for agricultural production, thus enhancing water security.

In terms of water security assessments for agricultural practices, the current thinking of the water profession, at least implicitly, is that the future will be an extension of the present but only with marginal improvements. However, this assumption is likely to prove to be fundamentally flawed. Agricultural water requirements, the biggest water user of the world, are highly likely to decline very significantly in most major countries during the coming decades. This will make the current water security assessments increasingly irrelevant. In reality, the world has simply no other choice if water security for agricultural production is to be assured in the future.

1.2.4 Circularity and Water Security

An important issue that has not received much attention in recent years is the implications for water security considerations when the circularity of water use is considered. Non-renewable energy-producing materials like coal, oil and gas break down into different components after they are used. This means energy-producing materials cannot be reused following their first and only use.

Water, however, is a renewable resource. It can be used, wastewater can be collected and treated properly, and then reused. This cycle can continue ad infinitum with good planning and management and steadily advancing technology. Depending upon the extent and quality of wastewater treatment, and reliabilities of the treatment processes, treated wastewater can be used for all purposes, including direct use for potable purposes.

Using properly treated wastewater as a direct source for domestic water is not a revolutionary idea, even though it has not been used in more than one city. The capital of Namibia, Windhoek, has been using reclaimed water as a direct source for potable use for over 50 years. This landlocked and very arid country and its capital do not have access to adequate sources of water. Thus, for over a half-century, the city has collected its domestic wastewater, treating it adequately and then using it directly for potable use (Tortajada and van Rensburg 2019). The city has not faced any health problem thus far for this long-term reclaimed water use.

Windhoek, in Africa, is an unlikely global pioneer for using reclaimed water for direct potable use. This confirms the old adage that necessity is the mother of invention. It was several decades later that the city-state of Singapore followed Windhoek's footsteps and started to use its treated wastewater. This is termed as NEWater. The quality of treated wastewater is better than the tap water currently supplied to its citizens. Thus, a major part of this high-quality treated wastewater is supplied for wafer industry which requires very high-quality water for manufacturing. The balance of reclaimed water is added to the reservoirs which supply Singapore's domestic water (Tortajada et al. 2013).

Water scarcity and uncertainty of water availability have resulted in several urban centres of the United States considering using reclaimed water, including for potable purposes (Smith and EPA 2017). Windhoek has shown for over 50 years, and Singapore and Orange County in California, United States, for nearly two decades, that reclaimed water can be safely used for drinking purposes without any health concerns. Technical considerations have been resolved decades ago. The main problem now is psychological. Many people are still not comfortable with the idea of drinking reclaimed water. However, as the total water demands increase, and cost-effective new sources of water are not available, many urban centres in different parts of the world will have no other alternative but to seriously consider this one to ensure their water security over the long-term. It is likely to be a challenge to convince people that reclaimed wastewater is safe to drink.

Climate change is making droughts in many parts of the world more common than ever before. In addition, droughts are often lasting for longer durations and often are becoming more intense. The millennium drought in Australia and the California drought of 2012–2016 are good examples. This means many urban centres, whether they prefer it or not, will be forced to consider the alternative of potable reuse since they are unlikely to have much choice if they wish to ensure their water security. Such developments will mean water use for domestic and industrial purposes are likely to become increasingly more circular in the future. Water will be used, wastewater will be collected and treated and then will be reused in homes and industries. This virtuous cycle is likely to become increasingly the norm in many cities in the coming 1–2 decades. Such developments, and their gradual acceptance by the general public as a source of domestic water supply, will significantly add to the future water security of urban areas in a positive manner.

Singapore has further strengthened its water security by capturing rainfall that falls in nearly 2/3rd of the city-state that is considered to be its urban catchment. The rain that falls in this large area is collected through an extensive network of drains, canals, rivers, stormwater collection ponds and reservoirs. Altogether, such drains, canals and rivers cover some 8000 km in length. All the rainwater collected is treated and then used as an important source for domestic and industrial water for the city-state. This has significantly contributed to its water security.

As climatic patterns become more extreme and unpredictable, stormwater drainage systems cannot only harvest rainwater but can also play an important role in controlling floods. For example, in Singapore, since January 2014, all new developments and redevelopments of 0.2 ha or more must implement "source" solutions to slow down stormwater runoff that could enter the public drainage system. These onsite storage measures include alternatives like detention tanks and raingardens.

Such special arrangements are helping Singapore to not only collect much of the rainwater that falls in its designated catchment area but also slow release of stormwater after heavy rainfalls to public drainage system is enabling it to manage urban flooding more effectively and efficiently.

All the above discussion indicates that the concept of water security is somewhat amorphous. Countries, and very specifically cities, have many policy options which can help them to strengthen their water security by steadily decreasing demands for domestic and industrial water uses, as well as expanding their supply by extensive treatment and reuse of wastewater, and pursuing non-conventional policies like collecting rainwater over much of any city and then using it for productive purposes. Significant reductions in agricultural water requirements in the future mean water security in 2030 can be assured with much less water than was necessary in 2010.

1.3 Climate Change

An important issue that the policymakers in general and the water professionals in particular, has not given much attention thus far is how likely future climate change characteristics can be seamlessly integrated with climatic fluctuations factors that have been regularly witnessed in the past and will continue to occur in the future. Historically, climatic fluctuations have been accepted as given facts, and the science of hydrology, over the past several decades, has advanced sufficiently to incorporate climatic fluctuations considerations adequately in terms of water resources planning, operations and management. We now have enough knowledge, experience, technology and management expertise to handle climatic fluctuations effectively. However, at present we do not have enough knowledge, experience and background to handle the risks and uncertainties that are inherent in the forecasts of climate change factors to plan, operate and successfully manage specific water resources projects adequately in a cost-effective manner.

One of the important reasons for this inability to incorporate climate change considerations in water projects is the continuing and prevailing disconnect between hydrologists and climatologists. One of the main mediums through which climate change impacts are often felt is through the lens of water. Climatologists dealing with climate change issues have been primarily concerned with averages, such as how average temperature may increase or how mean sea level may rise in the future. In contrast, water professionals are not much interested in average values: they are only of limited interest to them. Planning, design and management of water projects are based on extreme hydrological events. For example, designs for urban flood management are not based on average rainfall, but on extreme rainfalls, like maximum rainfall expected in 50 or 100 years, depending on cities and damages they may cause. Estimating the maximum likely rainfall over a city, even by 2070, to design an efficient and cost-effective stormwater disposal system under changing climate as well as other factors like land-use changes and extent of urbanisation, is now more of an art rather than exact science. Cities that currently design stormwater drainage systems so that they can withstand one in a hundred-year rainfall face even more uncertainties than ever before in history because of climate change.

The situation is even worse for major hydraulic infrastructures like large dams for which the current practice is to estimate the maximum probable flood which may occur once in 500 years, or even once in 1000 years for a few large and strategic dams. Estimating such floods over a very long return period with any degree of certainty has always been difficult in the past. Changing climate and other major factors that could influence their design, like vegetation covers, rainfall patterns, levels of urbanisation, land use patterns, afforestation/deforestation, evolving societal attitudes to and perceptions of acceptable risks, and host of other hydro-climatic, social, economic and political factors, have made it an exceedingly complex and difficult process. Consequently, the risks of over-design or under-design of major hydraulic structures have increased manifold because of the high levels of uncertainties associated with each individual factor that needs to be considered. At our present state of knowledge, climate change has made a difficult task almost impossible.

Probable maximum floods of large dams are generally estimated by considering the worst hydrological and meteorological conditions that may occur simultaneously over the catchment area. Such estimates have always been conservative. The final estimates always depended on the judgment, experience and risk-tolerance levels of the specialists concerned, even before the climate change era.

If to all these earlier complexities, uncertainties of climate change are superimposed, the reliability of the final estimates are difficult to predict. As the risks of over-design or under-design have increased significantly, the final estimates of costs of water projects may vary significantly depending on the levels of the design floods. This may result in a decision not to construct the project because of high-estimated costs. Alternatively, if maximum probable floods are under-estimated, and the structure is built, there is a real danger that it may fail at some time creating catastrophic consequences. At the current stage of knowledge, it is not possible to say whether a structure is properly designed, over-designed or under-designed because of estimating unprecedented runoffs of rivers due to climate and other change factors. The risks and uncertainties associated with such estimates are significant. This is one of many issues which has not received adequate attention, either from climatologists or water specialists.

Currently, the primary means of forecasting future climate is through the use of global circulation models (GCMs). There are now some 40 different such models. Even at the levels of large countries, the various GCMs do not give similar and consistent results (Strzepek and Smith 1996). This is not surprising since the climate is a coupled and nonlinear chaotic system. Even though our understanding of hydro-climatological factors has increased significantly in recent years, there are many climate processes that are not yet fully understood. Accordingly, these complex processes have to be simplified for constructing the GCMs, thus introducing uncertainties in the predicted results.

In addition, water planning is generally done at river basin or sub-basin levels. Unfortunately, at present state of knowledge, downcasting GCMs to forecast river flows at river basin or sub-basin levels, whichever may be the unit of planning, give results whose reliability is basically unknown. Urban centres consider stormwater management at city levels, which are even at a much smaller scale than river basins. The GCMs are ill-suited to forecast possible future climate scenarios at river basin, sub-basin or city levels (IPCC 2014).

1.4 Concluding Remarks

There is no question that changes in climate in the coming decades will affect how water resources activities are planned, designed, constructed and operated. Social, economic, political, environmental and institutional implications of climate change will be very significant in the future, both over space and time. These are, and will continue to be, complex, nonlinear and interrelated issues, with numerous known and unknown feedback loops which are not fully understood, appreciated, or even known at present. Lack of understanding of how various physical, social, economic, environmental and political forces may interact with each other, over space and time, as well as lack of reliable data and information over a reasonable period of time, are only two factors which currently prevent most national and international organisations to make reasonably reliable and actionable predictions of future climate scenarios for water planning and management.

At our present state of knowledge, there are numerous uncertainties which will continue to handicap the water profession to ensure water security of individual nations and cities due to the risks posed by climate change. These include, but are not limited to, future global emission scenarios, predicting how these are likely to affect future global, regional and local rainfall and temperature patterns over time and space, interpreting their overall impacts on the hydrologic cycle at different scales, assessing types and extent of scientific and technological breakthroughs that may be expected in the coming years which would enable us to better understand, predict, ameliorate and adapt to the various climate change scenarios, and their potential impacts. These are likely to be some of the major challenges that will continue to confront the water and the climate professions for many years to come.

While climatic uncertainties are many, and it will take time to understand and appreciate them properly, future water security can be reasonably assured by making water management and use practices and processes increasingly more efficient and equitable. As discussed earlier in this chapter, the world's water management practices have been on an unsustainable path for decades. These can be substantially improved so that significantly more can be done with less quantities of water. There are numerous examples from different parts of the world where good practices are delivering excellent results with less amounts of water. All such good practices need to be identified and properly documented especially in terms of the enabling conditions which made such results possible. These attempts would very significantly improve the water securities of individual cities, states and nations.

For successful and intelligent planning of the water sector within an overall framework of sustainable development, knowledge needs to advance much more than what is available at present. Meeting these challenges successfully and within a reasonable period of time will depend on going well beyond climatological-hydrologic modelling. Policies for adaptation and viable strategies for cost-effective mitigation measures have to be formulated on the basis of their overall effectiveness. The policies formulated have to be properly implemented. Equally, in the areas of water security and climate change, there are many factors which affect them that are likely to change over time and space. Thus, it will be essential that after a long-term plan is formulated, to ensure water security, it be reviewed rigorously to incorporate any changes necessary, every 3–5 years.

Above all, formulating long-term plans for ensuring water security and implementing them properly will need political leadership in all countries to put water higher-up in the political agenda over the long-term. Water security cannot be assured by only short-term and ad-hoc interest on the issues only when a serious flood, drought or natural disaster occur, as has been the case in nearly all parts of the world. It will require long-term sustained commitment from the national and state political leaders who should consider water security to be an important issue. This, sadly, is missing at present in nearly all countries of the world.

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