Water Resources Development and Management

Asit K. Biswas
Cecilia Tortajada *Editors*

Water Security Under Climate Change

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Foreword by The Right Honourable Nicola Sturgeon MSP, First Minister of Scotland

Water is the crucial underpinning of all life on earth, with huge social, environmental and economic significance. And water is undoubtedly where many of the most challenging impacts of climate change are being seen and felt. Like the rest of the world, Scotland too is increasingly experiencing the impacts of climate change on our water environment.

In this year when COP26 comes to our great city of Glasgow, no-one can be in any doubt about the importance of action on climate change. Not only has the world had to contend with the impacts of the global COVID-19 pandemic in 2021, but yet again we have seen record high temperatures in many parts of the globe, including Scotland, as well as devastating wildfires and lives tragically lost through flooding, all commonly agreed to be exacerbated, if not directly caused, by climate change.

As a Hydro Nation, Scotland is a country that recognises the sustainable, responsible management of our water resources is crucial to developing a flourishing low-carbon, climate-resilient economy. Water is a critical resource in most key sectors of the Scottish economy, particularly manufacturing, agriculture, food and drink, tourism and energy. But it is also a high-performing sector in its own right with a diverse supply chain, an established innovation support ecosystem, world-leading research base and a highly regarded governance and regulatory framework.

While we are fortunate in Scotland to have an abundance of water, we recognise the pressing importance of action to improve water security across the globe. As a small, but responsible nation, Scotland is helping to lead the way on the sustainable management of water resources and sharing our knowledge with and learning from our partners around the world.

Urgent, collective action on climate change is required not just across Scotland but right across the world. Governments, organisations, individuals and businesses all need to work together to meet the challenge of climate change. No one can doubt the importance of COP26 — we need to harness the best ideas to improve our understanding, galvanise ever more effective action and provide inspiration that we can build on.

I am delighted that this publication has been brought forward to coincide with COP26, and that work in Scotland is reflected in the book. I am sure you will agree it provides an important contribution to the discourse and understanding of water security issues in the light of climate change.

Nicola Sturgeon
First Minister of Scotland
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Foreword

Climate change is undoubtedly one of the greatest challenges of our time. It is transgenerational, transcends borders, and if we do not act urgently, we will continue to see the devastating impact of global warming on our planet. From more intense and frequent droughts and dangerous weather, to rising sea levels and warming oceans, this is having an impact on us all.

Now, more than ever, we must prioritize our oceans, seas, rivers, lochs and lakes. Water is precious and of vital importance to ecosystems and human societies, from sustaining life, cooking and agriculture to energy, sanitation and transport. We often have the luxury in the Western world of forgetting how much we rely on safe, clean and sustainable sources of water. The effects of human activity on land and water are now extensive, and if we do not protect and prioritize clean and green water management, then some of these changes caused by humanity may be irreversible.

The impact of climate change on water is also compounded by a number of other factors. As our global population grows and we see increased urbanization, and as we look to transition from finite energy resources, we are placing unprecedented pressure on water systems. The only way to achieve sustainable development and preserve safe and clean water resources for our planet is to achieve water security. In *Water Security under Climate Change*, the editors Profs. Asit K. Biswas and Cecilia Tortajada use their extensive knowledge in water management and policy to bring together world-leading authorities and policy-makers to guide us through the challenges and risks our water systems face and discuss how societies can work towards the wider goal of sustainability through effective water security.

The United Nations declared 2018–2028 the Water Action Decade, with the overarching goal to avoid a global water crisis. This will require humanity to be innovative and research-driven and learn from those who are leading the charge for environmental change. My own home country of Scotland is one of these leaders in sustainability. Scotland has some of the most ambitious climate targets in the world, and as a first step in response to the climate emergency, the Scottish Government introduced Scotland's Climate Change Bill with a net zero target for all greenhouse gases by 2045. In 2020, Scotland generated the equivalent of 97.4% of its electricity demand from renewables (Scottish Government 2021) and industry body Scottish

Renewables said output had tripled in the last decade, with enough power for the equivalent of seven million homes (Scottish Renewables 2021). In regard to water security and sustainable water management, Scotland has developed an innovative Hydro Nation strategy to make Scotland a nation where water resources are developed sustainably to bring maximum benefit to the Scottish economy.

Indeed, it is the city of Glasgow, home to my institution the University of Glasgow, which has the greatest potential to support Scotland as a Hydro Nation by becoming a global knowledge hub for research, teaching and technological innovation for water-related issues. This year, 2021, the city of Glasgow is due to play host to the 26th United Nations Climate Change Conference (COP26). This is an exciting opportunity to demonstrate that Glasgow—and Scotland—are committed to play their part in tackling climate change and protecting the planet for future generations. The venue for COP26 will be the Scottish Event Campus, aptly located on the banks of the River Clyde, the most important waterway in Scottish history and identity, and the focal point of the Clyde Mission. The Scottish Government's Clyde Mission has ambitions to use the Clyde to drive sustainable and inclusive growth for the city, the region and Scotland. The River Clyde was once synonymous with shipbuilding, engineering and industrial growth, and communities have settled along the riverbanks since the Palaeolithic era, with prehistoric canoes unearthed in the river. The Clyde sustained communities in the Kingdom of Strathclyde during the Roman occupation of Britain. In the thirteenth century, the first bridge was built over the river: an important step in Glasgow's development into a city and in the centuries that followed transforming the Clyde into a vital trade route for exporting and importing resources from the rest of the world.

Since 1451, the University of Glasgow's history has been intertwined with that of the River Clyde, and even today, the University's archives are home to a collection of hundreds of business documents detailing vessels built on the Clyde when Glasgow was at the height of its shipbuilding legacy. It is incredibly important for the University of Glasgow to maintain this relationship with the river flowing through the heart of our city and to ensure we are playing our part in unlocking the potential of the river to be transformational for local communities. Key to the University's contribution in this endeavour is the development of the Glasgow Riverside Innovation District (GRID). Encompassing both banks of the River Clyde, GRID offers the city the chance to reimagine our proud industrial heritage for the twenty-first century and to establish Glasgow's leadership in the hi-tech industries of the future. The GRID represents the changing civic nature and role of Universities beyond their traditional academic one, as a key anchor organization supporting the delivery of national government ambitions for inclusive and sustainable growth, by strengthening links between place, academia and research. The areas surrounding the River Clyde were hit hard by deindustrialization and still feel the effects of the loss of shipbuilding and heavy industry today. By reinvigorating the River Clyde and its surrounding areas, the river can once again become a key driver in Glasgow and Scotland's economic development, recognizing the riverbank as a vital organ of regeneration and learning from experiences in comparable cities across the world.

The Clyde Mission and regeneration of the Clyde Waterfront is a major pillar of the University of Glasgow's work. However, our institution is also involved in a multitude of initiatives aimed at preserving and protecting water as a vital natural resource and in supporting those communities who live alongside watercourses and coastlines across the world.

One of the most concerning factors of climate change is the impact it has on shifting ecosystems, and our rivers and fluvial ecosystems are particularly vulnerable. According to the UK Rivers Network, climate change impacts on rivers will include changes in water quality, impacts on wetland plants and animals, biodiversity loss and an increase in periods of intense, heavy rainfall leading to an increased risk of flooding (LSE 2021). Indeed, the 2017 Committee on Climate Change's UK Climate Change Risk Assessment 2017 Summary for Scotland notes that annual rainfall over Scotland has increased since the 1970s to a level about 13% above the average for the early decades of the twentieth century (Climate Change Committee 2017a). At the University of Glasgow, experts are working on a variety of research strands to establish how societies can adapt to climate risks, especially flooding. For example, experts from the University's Water and Climate Research group have been probing a novel artificial intelligence (AI) approach for flood hazard mapping, and colleagues at the University are leads partner in the EU-funded OPERANDUM project (OPEn-air laboRAtories for Nature baseD solUtions to Manage environmental risks) which focuses on disaster risk reduction to hydro-climatic hazards. Colleagues are also involved in research into the potential to use Nature-based Solutions (NbS) to mitigate flooding and have also been working across borders with counterparts in countries such as Sweden and the Philippines to understand and monitor the effects of climate change on rivers and flooding. The Living Deltas Hub, led at the University of Glasgow, also researches coastal tipping points in deltas across the world to understand when a social–ecological system can tip from one state, to another. If a piece of coastline erodes rapidly, the land disappears and so do any social activities on this land, including the loss of homes and livelihoods. The Hub is working to understand the biophysical, social and economic mechanisms that explain erosion, with a specific focus on mangrove systems, with an aim to propose solutions that improve the conservation or restoration of mangrove systems in the deltas covered by the project. There are several lessons to be learnt from this research, including the approach used by the Hub to understand the impact of plant life on waterways and developing Nature-based Solutions to strengthen resilience of waterways.

The University of Glasgow is also home to the National Centre for Resilience (NCR) at our Dumfries campus, which works with Scotland's Universities, researchers, policy-makers, emergency responders, volunteers and communities to build Scotland's resilience to natural hazards. Furthermore, the University's James Watt School of Engineering Water and Environment research team works closely with partners across the world to investigate sustainable management of the environment, extracting energy and resources from waste and making our rivers, water infrastructure, water and wastewater services resilient to climate change. The University has invested heavily in some of the best equipped and environmental

laboratories and hydraulic facilities in the UK to support this research, and we believe we have an important role to play in sharing our knowledge and expertise and contribute to Scotland's place as a Hydro Nation.

The University of Glasgow was the first university in Scotland to declare a climate emergency in May 2019, and to further reflect our commitment to the sustainable agenda, we also launched a Centre for Sustainable Solutions in 2020 to support interdisciplinary, cross-campus and cross-sectoral solutions to climate change. We are also a key contributor to the COP26 Universities Network, a growing group of more than 40 universities working together to raise ambition for tangible outcomes from COP26. There is an appetite in Glasgow, in Scotland and across the international higher education sector to do more together to reverse climate change. For us, in Glasgow, we have ambitions to secure our place on the world map as leaders in water and climate research, alongside our world-changing teaching, training and innovation.

Universities have shown our capacity to innovate rapidly during the pandemic (through vaccine development, diagnostics and genomic sequencing of the virus), and given the right support and backing, the sector will also be capable of developing rapid and innovative solutions to the climate emergency. The post-pandemic environment presents the opportunity for accelerated collaboration and the establishment of alliances between academia, industry, government and other bodies to ensure efficient use of resources and the sharing of skills, strengths and best practices. Climate change is a complex issue that cannot be solved by one institution or actor alone and instead requires a diverse set of knowledge, expertise, skills and experience, particularly when it comes to water security and preserving our most important global resource.

Scotland may only be small geographically, but we have around 19,000 km of coastline (approximately 8% of Europe's coast) (Marine Scotland Information 2021). We are home to 90% of the UK's surface freshwater (Climate Change Committee 2017b) and have some of the world's cleanest drinking water, with 99.1% of public drinking water of a high quality (Health Protection Scotland 2019). Our water is not just of great importance to our natural heritage and identity, but is also a precious economic resource and a major portion of our overall natural capital worth £291 billion (Scottish Government 2019). All of this, coupled with a global reputation for research excellence and some of the brightest minds working to produce creative solutions to our most pressing global challenges, means that we are well-placed to pave the way for a sustainable blue future and protect our water for future generations to come.

Professor Sir Anton Muscatelli
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Preface

Over the long term, water security and climate change could become serious existential issues for many parts of the world unless water governance practices are improved substantially and effective climate change adoption measures are implemented in timely manner. At the time of writing this preface, in July 2021, the world is witnessing unprecedented extreme climatic events, including an extensive heat dome and very high temperatures and extensive forest fires in British Columbia and the Western United States; heavy flooding in Germany, Belgium and the Netherlands; and repeat serious droughts in California and other Western states of the USA, parts of Brazil and many other parts of the world. Between 1998 and 2017, droughts have affected at least 1.5 billion people and have resulted in global economic losses of at least $124 billion. It is highly likely that during the next two decades lives lost due to floods, droughts, forest fires and landslides and economic losses suffered due to extreme climatic events would increase to new heights that were not considered to be likely even five years ago.

In terms of water security, much of the world has been on an unsustainable development path for the last several decades. In earlier times, levels of population and urbanization were lower than what they are at present, total water demands could be met most of the times, and provision of adequate quantity of water of reasonable quality was not a serious and unmanageable issue in most parts of the world. However, consistently poor governance practices, including inefficient functioning of water-related institutions, have contributed to the steady worsening of water security conditions all over the globe.

Water security of individual nations has been further exacerbated since water has never been high up in the political agenda on a sustainable basis in any country of the world, except Singapore. As a general rule, water becomes a politically priority issue only when there is a serious drought or flood. As soon as these extreme hydrological events are over and the media loses its interest in covering them, water invariably disappears from the political agenda.

Water security over the long term can only be achieved when there is sustainable interest of senior policy-makers to resolve related problems. It takes time to prepare a realistic and implementable plan to ensure water security, build necessary water-related infrastructure, make certain it is managed and operated properly and on a regular basis, establish necessary legal, economic and behavioural instruments and functioning institutions to promote good governance. To achieve water security, it is also necessary to establish enabling conditions that will allow adoption of technological advances.

The world has enough knowledge, experience, technology and investment funds to ensure it becomes water secure within the next 10–20 years. A main concern is that these are not necessarily utilized. Regrettably, there are no signs that the current poor governance practices are likely to change any time soon in most countries of the world. Incremental improvements have been the order of the past decades, which have prevented formulation and implementation of business unusual practices.

In contrast to water security, climate change is full of uncertainties that are unlikely to be resolved with any degree of certainty over the next several decades. While much of the current discussions have been based primarily on greenhouse gas emissions, average global temperature rises and average sea level rise, there are many other factors which could and would affect the climate in specific regions. This, in turn, will affect their water security. Among these factors are number and structure of population, extent of urbanization, rates and types of economic growth, types and extent of energy use, agricultural practices and production, policies of individual countries, technological developments and rate and extent of their adoption, changing social norms, perceptions and value systems of different societies, formation of different feedback loops and a host of other associated factors.

Even if perfect climate models can be developed, which is unlikely for decades to come, uncertainties will always exist because of social, economic, political, institutional and human factors. Uncertainties, however, do not mean that it is not possible to formulate and successfully implement effective adoption measures. What this means is that countries need to make long-term adoption plans for water security due to climate change, which should be rigorously and regularly reassessed, in the light of new knowledge, availability of more and reliable data, technological developments, scientific breakthroughs and changes in societal perceptions and values and other similar factors.

A very good example is the case of Singapore. It already has a water security plan for 2060 which explicitly considers climate change impacts. This plan will be regularly and rigorously reassessed every five years by the cabinet, and necessary changes will be made in all relevant policies.

The present book contains a series of papers on water security under climate change which were especially prepared by invited authors from different parts of the world, for publication before the COP26 event, which will be held in Glasgow, UK, in October-November 2021. We are most grateful to Sir Anton Muscatelli, Principal and Vice Chancellor, and Ms. Bonnie Dean, Vice Principal, University of Glasgow, and Barry Greig, Hydro Nation Manager, at the Scottish Government

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Part I
Perspectives

Chapter 1
Ensuring Water Security Under Climate Change

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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.

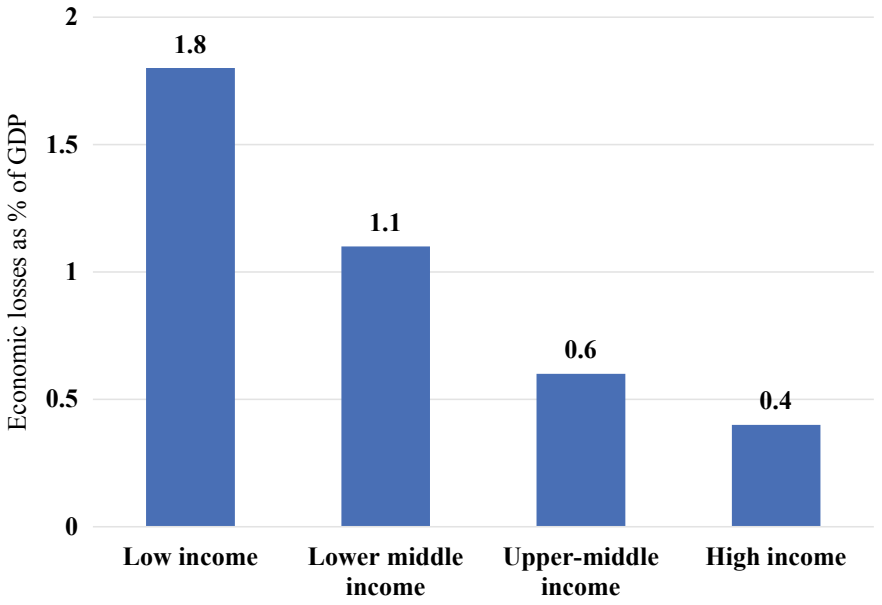

Fig. 1.1 Economic losses due climate-related disasters as % of GDP, 1998–2007. *Source* Adapted from Wallemacq and House (2018)

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

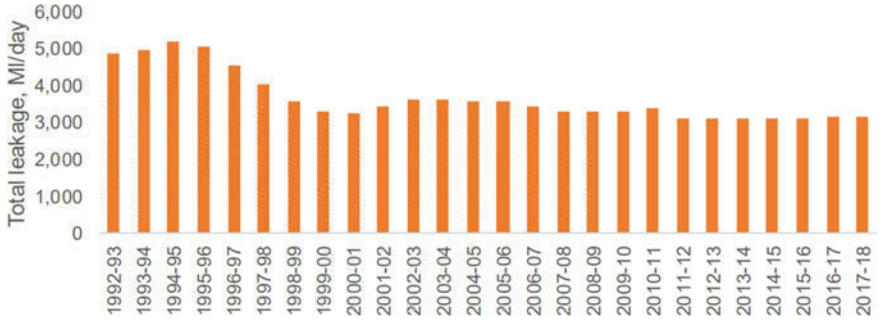

Fig. 1.2 Historical leakage in England and Wales. *Source* PwC 2019

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