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The United Nations World Water Development Report 2020

WATER AND CLIMATE CHANGE

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The United Nations World Water Development Report 2020

WATER AND CLIMATE CHANGE

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Foreword

by **Audrey Azoulay**, *Director-General of UNESCO*

The climate is changing, and our world is in danger.

Around one million animal and plant species are facing extinction. Freshwater species have suffered the greatest decline, falling by 84% since 1970. Humans are also affected: around four billion people currently experience severe physical water scarcity for at least one month per year, a situation that has been exacerbated by the climate crisis.

As the planet warms, water has become one of the main ways we experience climate change.

And yet the word “water” rarely appears in international climate agreements, even though it plays a key role in issues such as food security, energy production, economic development and poverty reduction.

This potential of water must be explored, given that our actions to reduce global warming are currently lagging behind our ambitions, despite wide adherence to the Paris Agreement.

That is the goal of the 2020 *World Water Development Report* on water and climate change. The report shows that water does not need to be a problem – it can be part of the solution. Water can support efforts to both mitigate and adapt to climate change. Wetland protection, conservation agriculture and other nature-based solutions can help to sequester carbon in biomass and soils. Improved wastewater treatment can help reduce greenhouse gas emissions and produce biogas as a source of renewable energy.

Coordinated and produced by UNESCO, this report is the result of close and continued collaboration within the UN-Water family. It was made possible thanks to the Government of Italy and the Regione Umbria, which have long supported the World Water Assessment Programme. I wish to thank all those who participated in this common endeavour.

Water is not just about development – it is a basic human right. It is essential to peace and security around the world. Addressing the issue of water is not a task to be taken lightly. We must rise to this challenge if we are to leave behind a world that future generations can live in.

Audrey Azoulay

Audrey Azoulay

Foreword

by **Gilbert F. Houngbo**, *Chair of UN-Water and President of the International Fund for Agricultural Development*

Climate change affects – and is affected by – global water resources. It reduces the predictability of water availability and affects water quality. Climate change also increases the occurrence of extreme weather events, threatening sustainable social-economic development and biodiversity worldwide. This, in turn, has profound implications for water resources. As such, climate change exacerbates the ever-growing challenges associated with the sustainable management of water. Conversely, the way water is managed influences the drivers of climate change.

Water, therefore, is the ultimate connector in the global commitments towards a sustainable future: the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) are highly dependent on improved water management. Within the Sendai Framework for Disaster Risk Reduction, adopted by UN Member States in March, 2015, water management is essential for reducing the occurrence and impacts of water-related disasters, which have the largest effect on society and people's livelihoods. And the implementation of the Paris Agreement is dependent on improved management of water resources. This is clearly acknowledged in many countries' Nationally Determined Contributions (NDCs) to reduce greenhouse gas emissions and adapt to the impacts of climate change under the UN Framework Convention on Climate Change. Adaptation initiatives related to water, for example, have been included as a first priority in many NDCs.

The 2020 edition of the UN World Water Development Report addresses the critical linkages between water and climate change in the context of sustainable development. It also serves as a guide for concrete actions to address these challenges. It outlines actions, supported by examples from across the world, in three areas: first, enabling people to adapt to the impacts of climate change; second, improving the resilience of livelihoods; and, third, reducing the drivers of climate change. Critically, measures to improve the efficiency of water use in agriculture - while at the same time ensuring water access for vulnerable groups such as smallholder farmers - is inextricably linked to multiple SDGs. These include those related to zero hunger (SDG 2), availability and access to water (SDG 6), climate action (SDG 13), and promoting the sustainable use of ecosystem services (SDG 15).

The Report concludes that reducing both the impacts and drivers of climate change will require substantial changes in the way we use and reuse the Earth's limited water resources. The experience and expertise needed to achieve this goal are brought together in the Report through UN-Water's Members and Partners. I would like to thank them all for the development of this flagship publication. I am grateful to UNESCO and its World Water Assessment Programme for coordinating the production of this report. I am confident that it will support policy makers in tackling the challenges of climate change by harnessing the wide-ranging opportunities that improved water management offers for adaptation, mitigation and resilience in a rapidly changing world.

Gilbert F. Houngbo

Preface

by **Michela Miletto**, *UNESCO WWAP Deputy Coordinator*
and **Richard Connor**, *Editor in Chief*

Climate change affects ecosystems, human societies and economies in a variety of ways, and water is the primary medium through which these impacts are felt. In some cases, these impacts are clearly obvious – for example through the increasing frequency and intensity of storms, floods and droughts. Increasing variability in the global water cycle implies greater water stress at different times and over different areas. The water-related impacts of climate change also include negative effects on food security, human health, energy production, and biodiversity, not to mention the daily livelihoods of the world's most vulnerable women, men and children. These in turn can lead (and have led) to rising societal inequities, social unrest, mass migration and conflict.

At the international level, a number of global frameworks have been adopted to address these challenges. However, while the 2030 Agenda for Sustainable Development (with its 17 SDGs, including specific goals for water and for combating climate change), the 2015 Paris Agreement and the Sendai Framework for Disaster Risk Reduction have all set ambitious goals and targets, actual progress towards meeting these global commitments has been lagging, especially in how each of these major global agreements pertain to water and climate change.

The 2020 edition of the United Nations World Water Development Report (WWDR) addresses the critical linkages between water and climate change in the context of the broader sustainable development agenda. The report is not meant to be a purely technical examination of the impacts of climate change on the hydrological cycle. Rather, the report focuses on the challenges, opportunities and potential responses to climate change – in terms of adaptation, mitigation and improved resilience – that can be addressed through improving how water resources are management and used, while providing water supply and sanitation services for all in a sustainable manner. In doing so, the report tackles two of the most critical crises the world will continue facing over the next several decades: Water (in)security and climate change.

When it comes to climate change, there has been a long-held belief that mitigation is mainly about energy, and that adaptation is mainly about water. Such a perspective greatly over-simplifies things. Of course, the water sector needs to adapt to climate change – from countering the effects of floods to addressing increasing water stress for agriculture and industry. But water management can also play a very important role in climate change mitigation. Specific water management interventions such as wetland protection, conservation agriculture and other nature-based solutions can help to sequester carbon in biomass and soils, while improved wastewater treatment can help reduce greenhouse gas emissions while supplying biogas as a source of renewable energy.

Improving adaptation in water management alone will not solve the climate crisis, nor will mitigation alone solve the water crisis or meet the SDG for water supply and sanitation. But ignoring water's role in climate change adaptation and mitigation, and failing to embrace the opportunities that the climate change frameworks offer to improve water management is certain to derail any significant progress towards solving either crises.

We have endeavored to produce a balanced, fact-based and neutral account of the current state of knowledge, covering the most recent developments, and highlighting the challenges and opportunities provided by improved water management in the context of climate change. Although primarily targeted at national-level decision-makers and water resources managers, as well as academics and the broader development community, we also hope this report will be particularly well received by scientists, practitioners and negotiators from the climate change community.

As the seventh in a series of annual, thematic reports, this latest edition of the WWDR is the result of a concerted effort between the Chapter Lead Agencies: FAO, SIWI, UNDP, UNESCO-IHP, UNESCO WWAP, UN-Habitat, UNU-INWEH, WHO, WMO and the World Bank; with regional perspectives provided by GWP, ODI, UNECA, UNECE, UNECLAC, UNESCAP, UNESCO Office in Nairobi and UNESCWA. The Report also benefitted to a great extent from the inputs and contributions of several other UN-Water members and partners, as well as from numerous scientists, professionals and NGOs who provided a wide range of relevant material. Similar to the other editions, the Report has been gender-mainstreamed and the cross-cutting gender dimension has been taken into consideration.

On behalf of the WWAP Secretariat, we would like to extend our deepest appreciation to the afore-mentioned agencies, members and partners of UN-Water, and to the writers and other contributors for collectively producing this unique and authoritative report that will, hopefully, have multiple impacts worldwide.

We are profoundly grateful to the Italian Government for funding the Programme and to the Regione Umbria for generously hosting the WWAP Secretariat in Villa La Colombella in Perugia. Their contributions have been instrumental to the production of the WWDR.

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We extend our most sincere gratitude to all our colleagues at the WWAP Secretariat, whose names are listed in the acknowledgments. The report could not have been completed without their professionalism and dedication. This includes our heartfelt appreciation to Stefan Uhlenbrook who served as UNESCO WWAP coordinator from November 2015 through September 2019, and who played a key role in the design and development of the report.

Last but not least, we dedicate this report to the youth of the world, whose inspirational calls for action on climate change have been heard loud and clear.

Michela Miletto

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Executive Summary

Climate change will affect the availability, quality and quantity of water for basic human needs, threatening the effective enjoyment of the human rights to water and sanitation for potentially billions of people. The hydrological changes induced by climate change will add challenges to the sustainable management of water resources, which are already under severe pressure in many regions of the world.

Food security, human health, urban and rural settlements, energy production, industrial development, economic growth, and ecosystems are all water-dependent and thus vulnerable to the impacts of climate change. Climate change adaptation and mitigation through water management is therefore critical to sustainable development, and essential to achieving the 2030 Agenda for Sustainable Development, the Paris Agreement on Climate Change and the Sendai Framework for Disaster Risk Reduction.

Impacts on water resources

Global water use has increased by a factor of six over the past 100 years and continues to grow steadily at a rate of about 1% per year as a result of increasing population, economic development and shifting consumption patterns. Combined with a more erratic and uncertain supply, climate change will aggravate the situation of currently water-stressed regions, and generate water stress in regions where water resources are still abundant today. Physical water scarcity is often a seasonal phenomenon, rather than a chronic one, and climate change is likely to cause shifts in seasonal water availability throughout the year in several places.

Climate change manifests itself, amongst others, in the increasing frequency and magnitude of extreme events such as heatwaves, unprecedented rainfalls, thunderstorms and storm surge events.

Water quality will be adversely affected as a result of higher water temperatures, reduced dissolved oxygen and thus a reduced self-purifying capacity of freshwater bodies. There are further risks of water pollution and pathogenic contamination caused by flooding or by higher pollutant concentrations during drought.

Many ecosystems, particularly forests and wetlands, are also at risk. The degradation of ecosystems will not only lead to biodiversity loss, but also affect the provision of water-related ecosystem services, such as water purification, carbon capture and storage, and natural flood protection, as well as the provision of water for agriculture, fisheries and recreation.

Much of the impacts of climate change will be manifested in the tropical zones where most of the developing world can be found. Small island developing states are typically environmentally and socio-economically vulnerable to disasters and climate change, and many will experience increasing water stress. Across the planet, drylands are expected to expand significantly. Accelerated melting of glaciers is expected to have a negative effect on the water resources of mountain regions and their adjacent lowlands.

Despite the growing evidence that the changing climate will affect the availability and distribution of water resources, some uncertainties remain, especially at local and basin scales. While there is not much disagreement about the temperature increases, which have been simulated by different General Circulation Models (GCMs) under specific scenario conditions, more variability and ambiguity exist in projected precipitation trends. Often, trends in extremes (heavier precipitation, heat, prolonged droughts) show a clearer direction than trends in annual precipitation totals and seasonal patterns.

Adaptation and mitigation

Adaptation and mitigation are complementary strategies for managing and reducing the risks of climate change.

Adaptation encompasses a combination of natural, engineered and technological options, as well as social and institutional measures to moderate harm or exploit beneficial opportunities from climate change. Adaptation options exist in all water-related sectors and should be investigated and applied where possible.

Mitigation comprises human interventions to reduce the sources or enhance the sinks of greenhouse gases (GHGs). While mitigation options are also available across every major water-related sector, they remain largely unrecognized.

International policy frameworks

Within the 2030 Agenda, water serves as an (often) unacknowledged but essential connecting factor for attaining the different Sustainable Development Goals (SDGs). As such, failure to adapt to climate change not only puts the realization of SDG 6 (the 'water goal') at risk, it also jeopardizes the achievement of most other SDGs. And while SDG 13 "*Take urgent action to combat climate change and its impacts*" includes specific targets and indicators, there is no formal mechanism linking SDG 13 to the goals of the Paris Agreement, resulting in parallel processes.

Although water is not mentioned in the Paris Agreement *per se*, it is an essential component of nearly all the mitigation and adaptation strategies. However, water *is* identified as the number one priority for adaptation actions in most of the intended nationally determined contributions (INDCs) and is directly or indirectly related to all other priority areas. Similarly, water is hardly mentioned in the Sendai Framework itself, even though water flows through each of the priorities for action and is central to all its seven targets.

The challenges of development, poverty eradication and sustainability are intricately interwoven with those of climate change mitigation and adaptation, especially through water. Given water's role in mitigating and adapting to climate change, water could play a connecting role across the SDGs and across policy frameworks such as the Paris Agreement.

Water resources management, infrastructure and ecosystems

Climate change generates additional risks to water-related infrastructure, requiring an ever-increasing need for adaptation measures.

Water-related extremes exacerbated by climate change increase risks to water, sanitation and hygiene (WASH) infrastructure, such as damaged sanitation systems or flooding of sewer pumping stations. The consequent spread of faeces and associated protozoa and viruses can cause severe health hazards and cross-contamination.

For water storage infrastructure, there is a need to reassess the safety and sustainability of dams, and to evaluate them for potential modifications or decommissioning, for the minimization of their environmental and social impacts, and for the optimization of their services.

In many regions of the world, aquifers present the largest storage capacity, often orders of magnitude greater than surface water storage. Groundwater is also more buffered from seasonal and multi-year climate variability and less immediately vulnerable than surface water.

It is increasingly necessary to consider 'unconventional' water resources in future planning. Water reuse (or reclaimed water) is a reliable alternative to conventional water resources for a number of uses, provided that it is treated and/or used safely. Desalination can augment freshwater supplies, but it is generally energy intensive and thus may contribute to GHG emissions if the power source is non-renewable. Atmospheric moisture harvesting such as cloud seeding, or fog water collection presents a low-cost and low-maintenance approach for localized areas where advective fog is abundant.

The bulk of the GHG emissions related to water management and sanitation either originates from the energy used to power the systems or the biochemical processes involved in water and wastewater treatment. Increasing water use efficiency and reducing unnecessary water consumption and water loss both translate into lower energy use and thus lower GHG emissions.

Wetlands accommodate the largest carbon stocks among terrestrial ecosystems, storing twice as much carbon as forests. Taking into account that wetlands offer multiple co-benefits – including flood and drought mitigation, water purification, and biodiversity – their restoration and conservation is of critical importance.

Disaster risk reduction

The current impacts and future anticipated risks associated with extreme events demand sustainable solutions for climate change adaptation and disaster risk reduction (DRR).

The range of available climate change adaptation and DRR strategies includes hard (structural) and soft (policy instruments) approaches. Hard measures include enhanced water storage, climate-proof infrastructure, and crop resilience improvements through the introduction of flood- and drought-resistant crop varieties. Soft measures include flood and drought insurance, forecasting and early warning systems, land use planning, and capacity building (education and awareness).

Hard and soft measures often go together. Urban planning, for example, can help increase resilience to flood risks by featuring drainage systems that provide spaces to safely collect and store floodwater. The city thus acts as a ‘sponge’, limiting surges and releasing rainwater as a resource.

Modern communication methods such as social media and mobile phone services provide significant opportunities to help improve communication and early warning effectiveness. Drought and flood monitoring systems are also an important component of risk reduction.

Mainstreaming gender and community involvement in decision-making processes are key elements to DRR strategies. Improved inter-agency coordination in water resources and disaster risk management is needed, especially in transboundary basins where it remains fragmented throughout most of the world.

Human health

Anticipated water-related health impacts of climate change are primarily food-, water- and vector-borne diseases, deaths and injury associated with extreme weather events such as coastal and inland flooding, as well as undernutrition as a result or food shortages caused by droughts and floods. Mental health impacts associated with illness, injury, economic losses and displacement may also be substantial, although difficult to quantify.

At the end of the Millennium Development Goals period (2000–2015), 91% of the global population used an improved drinking water source and 68% used improved sanitation facilities. Much remains to be done to reach the new, higher levels of safely managed water supply and sanitation services as defined under the SDGs for the 2.2 billion and 4.2 billion people respectively who lack this superior level of service.

Climate change is likely to slow or undermine progress on access to safely managed water and sanitation, and lead to ineffective use of resources if systems design and management are not climate-resilient. By extension, progress on the elimination and control of water- and sanitation-related disease will also be slowed or undermined by climate change.

Food and agriculture

The specific challenges for agricultural water management are twofold. The first is the need to adapt existing modes of production to deal with higher incidences of water scarcity and water excess (flood protection and drainage). The second is to 'decarbonize' agriculture through climate mitigation measures that reduce GHG emissions and enhance water availability.

The scope for adaptation in rainfed agriculture is determined largely by the ability of crop varieties to cope with shifts in temperature and to manage soil water deficits. Irrigation allows cropping calendars to be rescheduled and intensified, thus providing a key adaptation mechanism for land that previously relied solely on precipitation.

In terms of equivalent tonnes of CO_2, the largest contribution to agricultural GHG emissions is made by the release of livestock methane through enteric fermentation and manure deposited on pasture. For forestry, the greatest opportunity for mitigation involves reducing the emissions attributable to deforestation and forest degradation.

Agriculture has two main avenues for mitigation of GHGs: carbon sequestration through organic matter accumulation above and below the ground, and emission reduction through land and water management, including adoption of renewable energy inputs such as solar pumping.

Climate-Smart Agriculture (CSA) is a recognized suite of well-informed approaches to land and water management, soil conservation and agronomic practice that sequester carbon and reduce GHG emissions. CSA practices help to retain soil structure, organic matter and moisture under drier conditions, and include agronomic techniques (including irrigation and drainage) to adjust or extend cropping calendars to adapt to seasonal and interannual climate shifts.

Energy and industry

The water-related effects of climate change generate risks to business and power generation. Water stress can put a halt to manufacturing or energy generation. Impacts will also carry into operational aspects, affecting the supply of raw materials, disrupting supply chains, and causing damage to facilities and equipment.

Energy is in the spotlight of climate change initiatives as about two-thirds of the world's anthropogenic GHGs come from energy production and use. There are a number of opportunities to mitigate GHGs and reduce water use at the same time. Reducing energy demand and increasing energy efficiency are starting points. One promising direction is the increased use of low-carbon renewable energy technology with little water requirements, such as solar photovoltaic (PV) and wind, the costs of which are becoming increasingly competitive with fossil fuel energy generation. While hydropower will continue playing a role in climate mitigation and adaptation of the energy sector, the overall sustainability of single projects needs to be assessed, taking account of potential water consumption through evaporation as well as GHG emissions from reservoirs, not to mention the potential ecological and socio-economic impacts.

For business, water stress is one of the main drivers for water reuse and efficiency. In concert with technology, a facility could look at day-to-day operations such as the use of washwater, and better monitoring and leak detection. On an expanded scale, a company might evaluate its water footprint and include those of its suppliers, which may have far-reaching effects if they are large water users.

Human settlements

The impacts of climate change on urban water systems include higher temperatures, reduced precipitation and more severe drought on the one hand, and increasing heavy precipitation and flooding events on the other. It is precisely these extremes that make the planning of urban space and the provision of infrastructure so difficult.

The physical infrastructure for delivery of water and sanitation facilities can also be disrupted, leading to contaminated water supplies and the discharge of untreated wastewater and stormwater into living environments. Vectorborne diseases such as malaria, rift valley fever, leptospirosis and others are often observed after flooding events.

Urban water resilience goes way beyond the traditional city boundaries. In cases where water supplies rely on distant watersheds, planning needs to look well beyond the city's boundaries and consider the long-term impacts of urban expansion on distant freshwater ecosystems and the local communities that also rely on them.

In small urban and rural settlements, use of water for agriculture and in some cases industrial applications results in reduced availability for domestic uses. Domestic supplies must be prioritized under the human rights to water and sanitation.

Nexus: Accounting for interlinkages

Adaptation and mitigation actions by one sector can directly influence its water demand, which can in turn augment or reduce the local/regional water availability (including quality) for other sectors. In cases of reduced water demand, such actions can lead to multiple benefits across sectors and boundaries, whereas increased water demand can result in the need for trade-offs over the allocation of limited supplies.

Water use requires energy. Therefore, any reduction in water use has the potential to reduce the energy demand from the water sector and thus help mitigate climate change (if said energy source is from fossil fuels). Conversely, energy production also requires water. With their very low water requirements, renewables such as wind, PV and certain types of geothermal power generation are by far the best energy alternatives from a water demand perspective.

Water efficiency measures in agriculture can increase water availability and reduce the energy needed for pumping, in turn further reducing the water needed for energy production. Increased use of renewable energy in agriculture (e.g. solar PV pumps) provide additional opportunities to lower GHG emissions and to support the livelihoods of smallholders. Since agriculture accounts for 69% of global water withdrawals, reducing food loss and waste could also have significant repercussions on water and energy demand, and thereby reducing GHG emissions.

Conservation agriculture allows soils to retain more water, carbon and nutrients, with additional ecological benefits. The biomass and soils of properly managed forests, wetlands and grasslands provide mitigation opportunities through carbon sequestration, with significant additional benefits in terms of nutrient cycling and biodiversity.

Improved approaches to the treatment of water, and especially wastewater, offer a range of mitigation opportunities. Untreated wastewater is an important source of GHGs. With more than 80% of all wastewater (globally) released to the environment without treatment, treating its organic matter prior to its release can reduce GHG emissions. The reuse of untreated or partially treated wastewater can reduce the amount of energy associated with water extraction, advanced treatment and, in cases where the wastewater is reused at or near the release site, transportation. The biogas produced from wastewater treatment processes can be recovered and used to power the treatment plant itself, rendering it energy-neutral and further enhancing energy savings.

Governance

Both climate and water management require mechanisms for oversight and coordination. Sectoral fragmentation and bureaucratic competition may pose serious challenges for the integration across scales. This calls for i) greater public participation to discuss and manage climate risk; ii) building adaptive capacities at multiple levels; and iii) prioritizing risk reduction for socially vulnerable groups.

‘Good governance’ involves adhering to principles of human rights, including effectiveness, responsiveness and accountability; openness and transparency; participation in the performance of key governance functions relating to policy and institutional arrangements; planning and coordination; and regulation and licensing. For the integration of substance, integrated water resources management (IWRM) provides a process to involve stakeholders across society, the economy and the environment.

Greater public participation to manage climate risk is suggested as a way to build adaptive capacities at multiple levels, avoid institutional traps and prioritize risk reduction for socially vulnerable groups. At the same time, scientific information and data also need to be made available at the local level and included as information into local multi-stakeholder decision processes.

While governments remain responsible for leading national climate mitigation and adaptation measures as well as water governance, the process of change is always coproduced. There are many indications that young people are increasingly concerned about climate change. Cities have also become forerunners of climate action in many countries, and leading companies have made commitments to reduce their water footprint and GHG emissions in order to address their contribution to water stress and climate change.

Poverty, discrimination and vulnerability are closely related and typically intersect. Women and girls from minority ethnic groups or from remote or disadvantaged areas may suffer multiple forms of exclusion and oppression. When disasters hit, such inequalities can become exacerbated, making it more likely that poor people are affected. Poor people are also likely to lose relatively more than the non-poor.

Finance

Current levels of financing are inadequate to reach the international community’s goal of universal availability and sustainable management of water and sanitation. Proponents of water projects could aim to increase the water sector’s share of climate finance and emphasize water’s ties to other climate-related sectors in order to ensure greater funding for water management.

Two promising trends are generating opportunities for water projects to access climate finance. The first is the increasing recognition of the mitigation potential within water and sanitation projects. This trend could be particularly advantageous, as mitigation made up 93.8% of climate financing in 2016, but water projects consisted of a fraction of 1% of that sum. The second trend is an increasing emphasis on financing climate adaptation.

Accessing climate finance can be competitive and difficult, especially for complex water projects that may transcend national boundaries. Bankable climate projects are those that have a clearly articulated link to climate change impacts, familiarity and strict compliance with funding procedures, and sometimes additional funding sources. In order to be considered bankable, projects hoping to use climate finance must explicitly address the causes and/or consequences of climate change. Projects that communicate and address risks, and capture co-benefits in other areas such as health, are also considered more bankable.

Differentiated strategies that specifically consider the resilience needs of marginalized groups should also be built into larger water–climate plans and projects.

Technological innovation

The challenges, in terms of technological innovation, knowledge management, research and capacity development, are to promote the generation of new tools and approaches through advanced research and development, and, equally as important, to accelerate the implementation of existing knowledge and technologies across all countries and regions. However, these actions will only lead to the intended outcomes if they are accompanied by awareness-raising, as well as educational and capacity development programmes, in order to widely disseminate the available knowledge and to stimulate the uptake of new and existing technologies.

Satellite-based earth observation can help identify trends in precipitation, evapotranspiration, snow and ice cover/melting, as well as runoff and storage, including groundwater levels. While remote sensing can reveal large-scale processes and features that are not easily observable via traditional methods, the temporal and spatial resolution may not be fully adequate for smaller-scale applications and data analysis. However, when backed with national statistics, field-based observations and numerical simulation models, remote sensing can contribute to a comprehensive assessment of climate change impacts related to water.

Evolutions in the field of data acquisition have been facilitated by high-speed internet networks and global coverage, as well as cloud computing and the enhancement of virtual storage capabilities. Wireless sensors for monitoring water consumption have been developed and are increasingly used to allow for remote water metering. Applications of big data analytics can help to obtain knowledge by processing the collection of continuous streams of water-related information and data, in order to extract actionable information and insights for improved water management. Citizen science and crowdsourcing have the potential to contribute to early warning systems and to provide data for validating flood forecasting models.

Regional perspectives

Domestic regulation of water resources development, use, conservation and protection forms the foundational pillar of water governance and is the prime instrument for the implementation of INDCs under the Paris Agreement.

While two-thirds of countries outline a general portfolio of water projects in their INDCs, only one in ten cite what could be called a detailed project proposal, and these originate either from domestic water planning processes or have emerged from previous climate funding proposals. However, the need for institutional reforms is well recognized in INDCs, often prioritized alongside infrastructure investments.

Regional approaches to support transformative shifts can play a critical role in national-level implementation by improving collaboration and coordination between responsible institutions; ensuring that action is based on sound information and evidence; and increasing access to both public and private finance for climate-resilient investment.

Sub-Saharan Africa

Impacts of climate variability on Africa's water resources are already acute, as exemplified by the recent decrease in rainfall in southern Africa. Water-related impacts of climate change on human health are also expected, through vector- and waterborne diseases (including by further challenging access to safe drinking water, sanitation and hygiene) and via malnutrition, given expected impacts on food security. In agricultural systems, especially in semi-arid areas, conventional livelihood-based approaches appear not robust enough to deal with the long-term impacts of climate change.

Policies and actions towards climate change adaptation and mitigation include: supporting resilience to droughts and floods through investing in and improving the climate resilience of WASH facilities; expanding social protection and introducing financial products like insurance; enhancing gender equality in the use and management of water resources; and improving water availability for agriculture through water harvesting, mulching and reduced tillage in rainfed systems.

Energy is politically important to fulfil the ambitions of many African countries in terms of economic transformation. It could provide a catalyst to encourage regional cooperation to address challenges at the water–energy–climate nexus, possibly opening up investment in regional power pools and the institutional mechanisms for energy trading.

Europe, Caucasus and Central Asia

Climate projections indicate increasing precipitation in northern Europe and decreasing precipitation in southern Europe. The Intergovernmental Panel on Climate Change (IPCC) highlights increasing challenges for irrigation, hydropower, ecosystems and human settlements in the region.

The key actions for more effective adaptation and more resilience to extremes in the region include: enhanced water efficiency and water saving strategies; monitoring and data sharing on water quantity and quality; improving coherence of climate change adaptation and water-related DRR; and attracting funding from multiple sources (e.g. international, national and private).

In transboundary basins, technical and financial assistance can be shared up- or downstream, from wealthier to poorer riparian countries. However, even where funds are available, transboundary water management can be politically difficult. This points to the need to find a politically salient entry point around which to build cooperation. In some cases, climate change itself can be the factor that opens up the opportunity for cooperation.

Latin America and the Caribbean

Climate variability and extreme events already severely affect the region. In Central and South America, observed streamflow and water availability changes are projected to continue, affecting vulnerable regions.

Rapid urbanization, economic development and inequality are among the key socio-economic drivers of pressure on water systems with which climate impacts intersect. Poverty is persistent in most countries, contributing to the vulnerability to climatic change. Economic inequality also translates into inequality in access to water and sanitation, and vice versa. Increasing risks of waterborne diseases have a greater impact on poor people. Vulnerability is also high in rural areas, with climatic factors limiting economic options and driving out-migration.

For many countries in the region, climate change occurs against a backdrop of high levels of intersectoral competition for water, including between urban areas, the energy and agriculture sectors, and ecosystem needs.

The limited explicit mention of transboundary water–climate issues in development strategies is symptomatic of wider challenges in cooperation on transboundary waters in Latin America and the Caribbean.

Asia and the Pacific

There is high variation and low confidence in projected water-related impacts of climate change at the subregional scale in Asia and the Pacific. The region is highly vulnerable to climate-induced disasters and extreme weather events, which are disproportionately burdening poor and vulnerable groups. Water-related climate impacts intersect with other socio-economic trends that impact water quality and quantity, including industrialization (which is reshaping sectoral demand for water and increasing pollution), population growth and rapid urbanization. The latter have also increased exposure to water-related natural hazards such as floods.

Climate change and increasing demand for water will put additional stress on the region's groundwater resources, which are already experiencing severe stress in some areas due to increases in demand for irrigation.

At the national level, identified priorities to accelerate water–climate action include: enhancing water governance and water productivity to manage competition between the water needs of agriculture, energy, industry, cities and ecosystems; promoting nature-based solutions that can curb emissions and increase resilience; and integrating climate change and DRR across the entire project and policy cycle.

Regional cooperation on investment and information, as well as on institutional areas such as governance, capacity and partnerships, is urgently needed in Asia's transboundary basins.

Western Asia and North Africa

Vulnerability to climate change is moderate to high across the region, with a generally increasing gradient from north to south. Runoff and evapotranspiration generally follow the same trends as precipitation, although evapotranspiration is limited by water scarcity.

The areas with the highest vulnerability to climate change are in the Horn of Africa, the Sahel and the southwestern part of the Arabian Peninsula, which comprise several of the region's Least Developed Countries. While their exposure to climate change varies, they all exhibit low adaptive capacity.

Intersecting with broad challenges of climate change and limited adaptive capacity are complex socio-economic and political dynamics, affecting water at the regional, national and subnational levels. Politicization and weaponization of water resources, displacement, and degradation of water infrastructure have been major challenges for countries affected by conflict. Inequalities in access to and control of water resources persist, especially across urban–rural and gender lines.

Regional stakeholders identified many priorities and opportunities relating to water, including: rendering urban development more sustainable; enhancing data, research and innovation; increasing the resilience of vulnerable communities exposed to floods and droughts, and threatened by food insecurity; furthering policy integration between mitigation, adaptation and sustainable development; and increasing access to finance, including via international climate funds and through the development of local markets and investment products.

The way forward

Given the cross-cutting nature of water and climate through different economic sectors and across society, trade-offs and conflicting interests need to be addressed at all levels in order to negotiate integrated and coordinated solutions. This requires an equitable, participatory, multi-stakeholder approach to water governance in the context of climate change.

There are increasing opportunities to more genuinely and systematically integrate adaptation and mitigation planning into water investments, rendering these investments and associated activities more appealing to climate financiers. Furthermore, various water-related climate change initiatives can also provide co-benefits such as job creation, improved public health, reduced poverty, the promotion of gender equality and enhanced livelihoods, among others.

Despite the mounting evidence that climate change is affecting the global hydrological cycle, much uncertainty remains when projecting its impacts over smaller geographical and temporal scales. However, this uncertainty must not be seen as an excuse for inaction. Rather, it should serve as an impetus to expand research, to promote the development of practical analytical tools and innovative technologies, to adopt no-regrets approaches, and to build the institutional and human capacity required to foster informed, science-based decision-making.

The need for greater cooperation between the water and climate communities exists well beyond the realm of scientific research. On the one hand, it is imperative that the climate change community, and climate negotiators in particular, give greater attention to the role of water and recognize its central importance in addressing the climate change crisis. On the other hand, it is equally (if not more) essential that the water community focuses its efforts to promote the importance of water in terms of both adaptation and mitigation, develop concrete water-related project proposals for inclusion in nationally determined contributions (NDCs), and strengthen the means and capacities to plan, implement and monitor water-related activities in NDCs.

Combining climate change adaptation and mitigation, through water, is a win-win-win proposal. First, it benefits water resources management and improves the provision of water supply and sanitation services. Second, it directly contributes to combating both the causes and impacts of climate change, including DRR. Third, it contributes, directly and indirectly, to meeting several of the Sustainable Development Goals (hunger, poverty, health, energy, industry, climate action and so on – not to mention SDG 6, the 'water goal' itself) and a host of other global objectives.

In an era characterized by a host of 'gloom and doom' studies and articles on climate change and other global environmental crises, this report proposes a series of practical responses, in terms of policy, financing and action on the ground, to support our collective objectives and individual aspirations to achieve a sustainable and prosperous world for all.

Prologue

The state of water resources in the context of climate change

Llamas on the Andean highlands (Bolivia).

WMO | Bruce Stewart

UNESCO-IHP | Wouter Buytaert, Anil Mishra and Sarantuyaa Zandaryaa

WWAP | Richard Connor, Jos Timmerman and Stefan Uhlenbrook

With contributions from: Rio Hada (OHCHR)

The Prologue provides an overview of the state of the world's water resources and the potential impacts of climate change on the hydrological cycle, including water availability and quality, water demand, water-related disasters and extreme events, and ecosystems. Knowledge gaps, limitations and uncertainties are also addressed.

Introduction

There is now strong scientific consensus regarding the human influence on the climate system and the role of anthropogenic emissions of greenhouse gases (GHGs) in global warming (IPCC, 2014a; 2018a). The rate of GHG emissions is at an all-time high (WMO, 2019). Even if emissions are brought in line with current political pledges on the nationally determined contributions (NDCs) under the Paris Agreement, the scientific community is highly confident that the global average temperature will surpass pre-industrial levels by at least 1.5°C after 2030 (IPCC, 2018a).

Climate change affects global water resources in multiple ways, with complex spatiotemporal patterns, feedback effects, and interactions between physical and human processes (Bates et al., 2008). These effects will add challenges to the sustainable management of water resources, which are already under severe pressure in many regions of the world (WWAP, 2012) and subject to high climate variability and extreme weather events. Notably, they affect the availability, quality and quantity of water for basic human needs, threatening the effective enjoyment of the human rights to water and sanitation for potentially billions of people. Although the effects of climate change can be highly idiosyncratic at the local scale (IPCC, 2019a), current trends and future projections indicate major shifts in climate, and more extreme weather events in many parts of the world (IPCC, 2014a). It is therefore paramount that water resources managers consider the potential impacts of a changing climate when managing water as a resource for society that is fundamental to sustainable development.

The hydrological changes induced by climate change imply major risks for society, not only directly through alterations in the hydrometeorological processes that govern the water cycle, but also indirectly through risks for energy production, food security, economic development and social inequalities, among others (Figure 1). Climate change adaptation and mitigation through water management is therefore critical to sustainable development, and necessary to achieve the 2030 Agenda for Sustainable Development, the Paris Agreement and the Sendai Framework for Disaster Risk Reduction.

Climate change

Scientific evidence that the climate system is warming is now unequivocal, with scientific consensus on the role of human activities. Anthropogenic GHG emissions have steeply increased since the pre-industrial era (Figure 2), and atmospheric concentrations of carbon dioxide, methane and nitrous oxide (Figure 3) are at levels unprecedented in at least the last 800,000 years (IPCC, 2014a; 2018a; WMO 2019).

Figure 1 Interactions between water and other major socio-economic sectors affected by climate variability and change

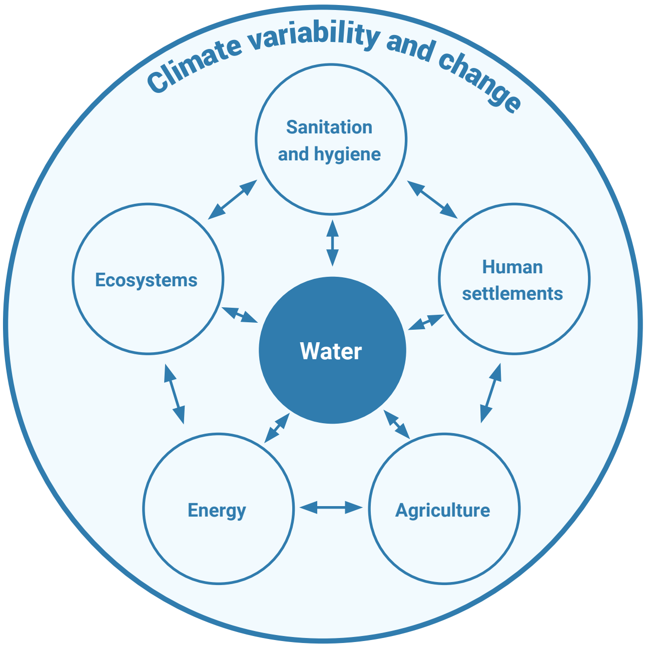
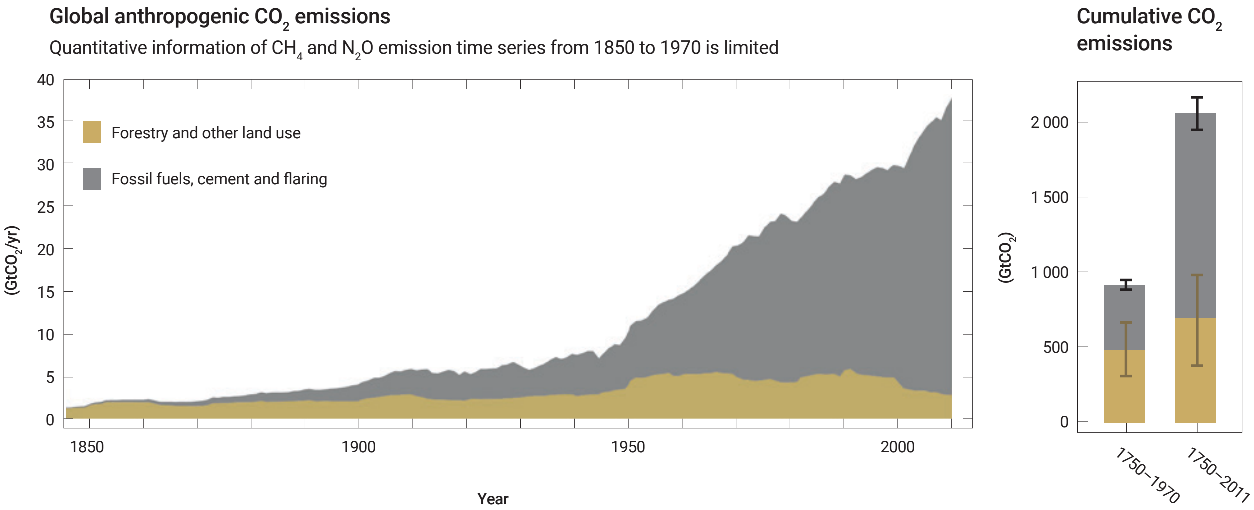


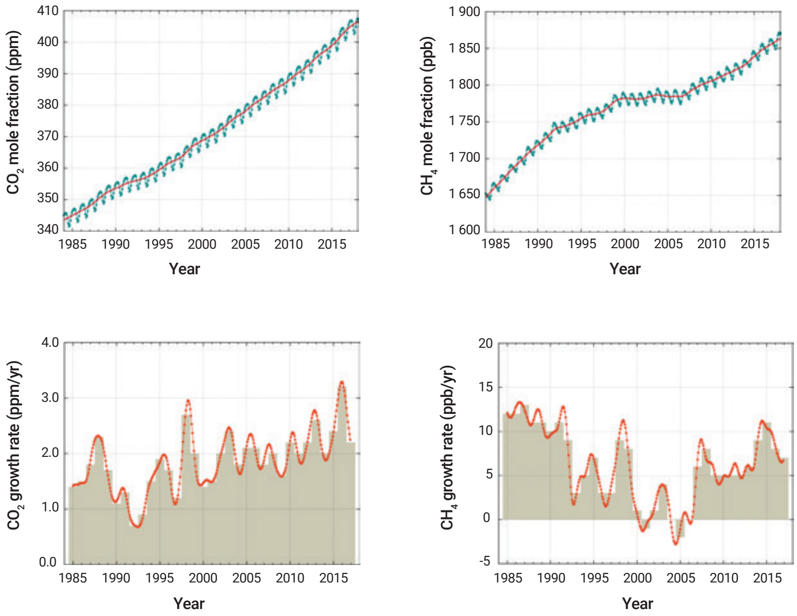
Figure 2 Global anthropogenic CO_2 emissions, 1850–2011



Source: IPCC (2014a, fig. 1.5, p. 45).

The effects of GHGs, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century (IPCC, 2014a). Globally, the average surface temperature of the planet has risen about 0.9°C since the 19th century (Figure 4). Most of this warming happened in the last 35 years, with five of the warmest years on record having occurred after 2010. According to latest data from the World Meteorological Organization (WMO) and the Copernicus Climate Change Programme, July 2019 matched, and maybe broke, the record for the hottest month since analysis began (WMO, 2019). Ocean water temperatures also show an increasing trend (Cheng et al., 2019).

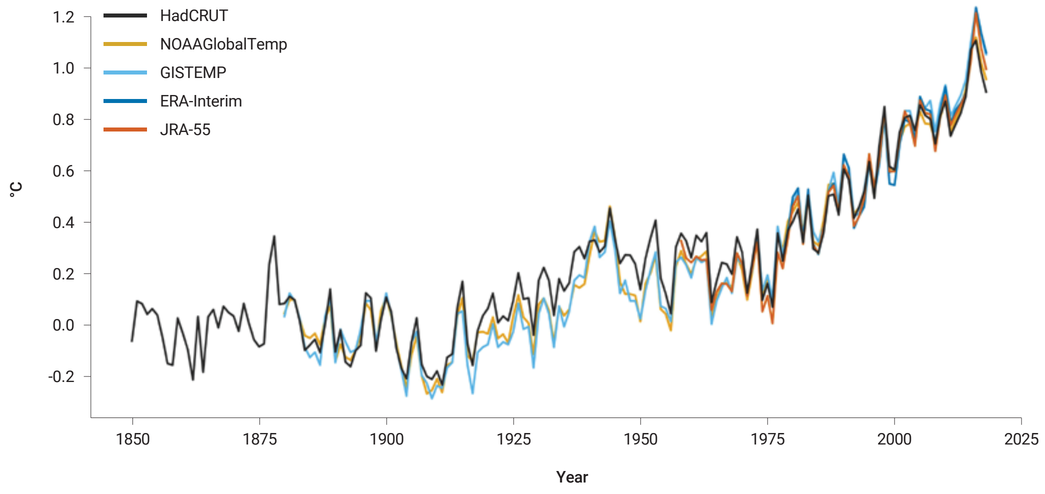
Figure 3 Increasing levels of greenhouse gases in the atmosphere



Note: Top row: Globally averaged mole fraction (measure of concentration) from 1984 to 2017 of CO_2 (ppm; left), CH₄ (ppb; centre) and N_2O (ppb; right). The red line is the monthly mean mole fraction with the seasonal variations removed; the blue dots and line show the monthly averages. Bottom row: Growth rates representing increases in successive annual means of mole fractions for CO_2 (ppm per year; left), CH_4 (ppb per year; centre) and N_2O (ppb per year; right).

Source: WMO (2019, fig. 3, p. 9).

Figure 4 Global mean temperature anomalies with respect to the 1850–1900 baseline for the five global temperature datasets



Source: Met Office. © British Crown Copyright.

Since the mid-20th century, changes in the intensity and frequency of extreme weather and climate events have also been observed. Several of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extremely high sea levels and an increase in the number of heavy precipitation events in a number of regions (Min et al., 2011).

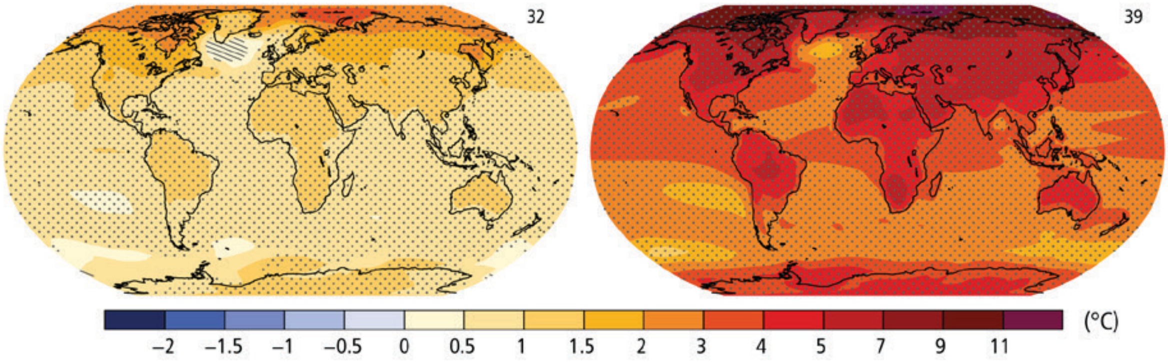
The continued emission of GHGs will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems (UNCTAD, 2016).

While there is a clear trend in temperature (Figure 5), trends in annual precipitation volumes are much more uncertain in many regions, for example in larger parts of the sub-tropics, where many of the Least Developed Countries are located. For example, under Representative GHG Concentration Pathway 8.5 (RCP8.5), General Circulation Models (GCMs) are in agreement on the future directions of precipitation amounts for only a third of the land surface (IPCC, 2014a). Large uncertainties in climate models, especially in the transition zones between regions with increasing and decreasing annual precipitation, do not preclude potentially large impacts on weather extremes and water resources. Even small changes in temperature and climate (i.e. low-end GHG scenarios) can have large impacts on water availability and extremes in particular.

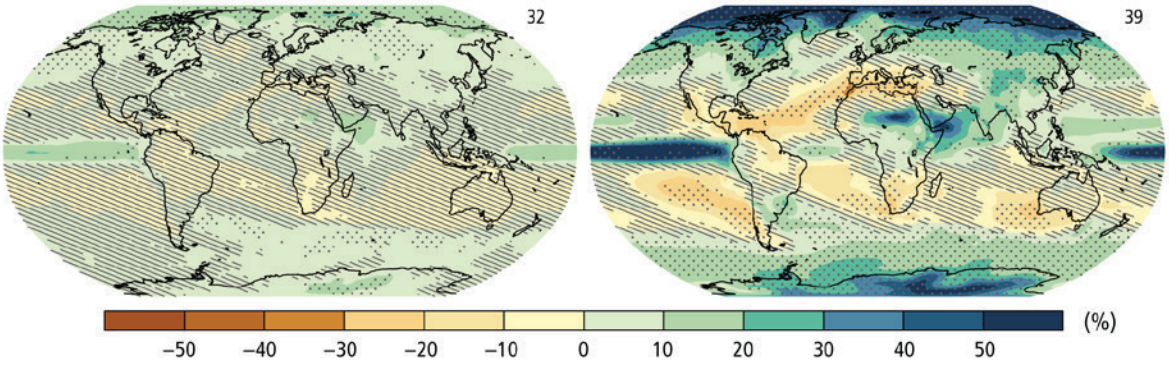
Figure 5 Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model mean projections

RCP2.6 **RCP8.5**

(a) **Change in average surface temperature (1986–2005 to 2081–2100)**



(b) **Change in average precipitation (1986–2005 to 2081–2100)**

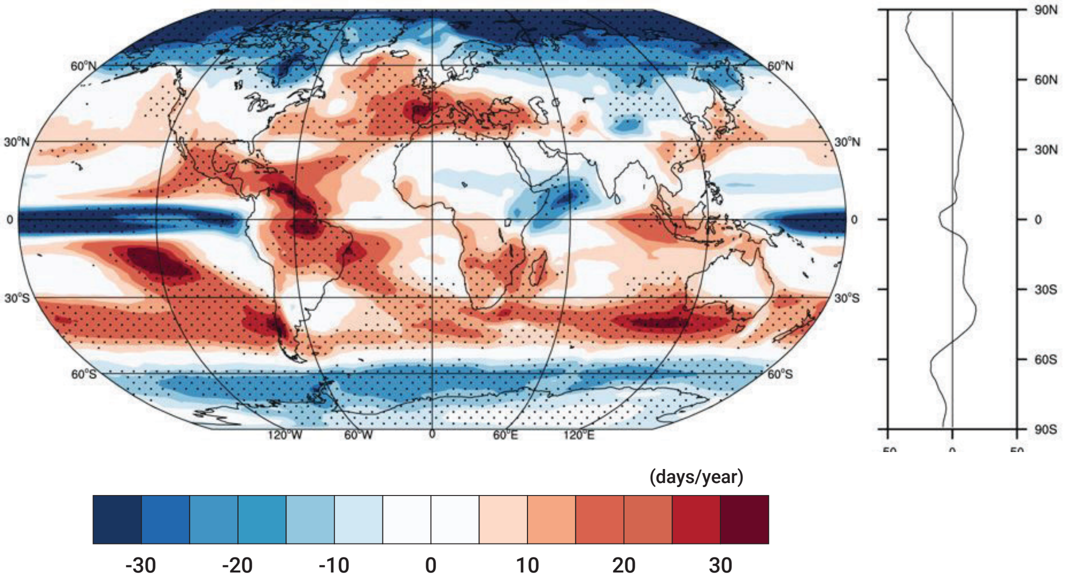


Note: The average of the model projections available for the 2081–2100 period under the RCP2.6 (left) and RCP8.5 (right) scenarios for (a) change in annual mean surface temperature and (b) change in annual mean precipitation, in percentages. Changes are shown relative to the 1986–2005 period. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling dots on indicates regions where the projected change is large compared to natural internal variability (i.e., greater than two standard deviations of internal variability in 20-year means) and where 90% of the models agree on the sign of change. Hatching (diagonal lines) on and shows regions where the projected change is less than one standard deviation of natural internal variability in 20-year means.

Source: Adapted from IPCC (2014a, fig. 2.2, p. 61).

More so than for annual averages for precipitation (especially in the subtropics), global models agree to a large extent on a future increase in extreme weather (Hattermann et al., 2018). Climate projections indicate with high confidence that extreme precipitation events will become more intense and frequent in many regions, but also that heatwaves will occur more often and last longer (Figure 6). The former will increase global flood risk (Hirabayashi et al., 2013), while the latter is expected to make droughts more intense (Trenberth et al., 2014). These risks are unevenly distributed geographically, and are generally larger for vulnerable people and communities in countries at all levels of development (IPCC, 2014a).

Figure 6 CMIP5 multi-model ensemble average mean change in frequency of dry days (days/year) by 2060–2089, relative to the historical period 1960–1989, using the RCP8.5 forcing scenario



Note: Stippling indicates areas where at least 70% of the models agree on the sign of the change. Graph to the right: zonal mean values.

Source: Polade et al. (2014, fig. 2).

For example, in West Africa, with the Niger as its main river basin, as well as in the region of the Upper Amazon, uncertainty in annual precipitation projections is very high. At the same time, there are strong indications that there will be a higher proportion of dry days, even in a climate that on average will become wetter (GIZ/adelphi/PIK, forthcoming) (see Section 9.1.3).

While there is a clear trend in temperature, trends in annual precipitation volumes are much more uncertain in many regions

In view of these and other threats posed by a changing climate, at the 21st Conference of the Parties (COP21) in Paris (December 2015), the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) reached a landmark agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low-carbon future. The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by limiting the global temperature rise this century to well below 2°C above pre-industrial levels, and to pursue efforts to limit the temperature increase even further, to 1.5°C.

But even if this ambitious goal is achieved, some of the current trends will continue, creating long-lasting or potentially irreversible changes. This must be taken into account in the management of water resources into the future.

Climate and water

The earth's climate and the terrestrial water cycle have a very close and complex relationship (Figure 7). Changes in climate variability and change will therefore propagate to affect water resources. For example, a rainfall deficit will reduce soil moisture, river flow and groundwater recharge, but the magnitude of these flow-on effects will depend on local conditions such as soil properties, geology, vegetation and water use.

Because of the different timescales of the involved processes, the impacts on groundwater deficit (although they are usually less pronounced than for surface water and come with a delay) may last for much longer than the original meteorological drought that caused them, thus initiating a 'memory effect' (Changnon, 1987). Floods, on the other hand, may have an impact on water availability, sanitation and other facets of human livelihoods through damage to key infrastructure and services.

At the same time, the hydrological cycle is itself an essential component of the climate system, controlling the interaction between the atmosphere and the land surface and providing feedback mechanisms for the transport, storage and exchange of mass and energy (Figure 7).

The linkages between the climate and water resources are affected by a variety of anthropogenic factors, including but not limited to land use and land cover change, water regulation and withdrawal systems, and water contamination. Through a combination of 'grey' and 'green' engineering, such as the construction of water resources infrastructure, and the development of agricultural and other water use practices, humankind has improved access to safe water supply and sanitation services throughout its history. Climate change will affect many of these strategies in numerous ways, and therefore require a new, climate-smart approach to water resources management.

Status of water-related impacts from climate change

Climate change affects the terrestrial water cycle through many different processes. Feedbacks and interactions between those processes, which are not all fully understood or measurable at relevant scales, make quantification and prediction of the consequences very difficult. Furthermore, water resources development and management have, historically, been undertaken under the assumption of stationarity[1] of hydrological time series (Milly et al., 2008). Whilst hydrological data collected in the past provide valuable information on processes and events, they are not necessarily indicative of the future hydrological regime. Furthermore, even when hydrological changes are detected, attribution of causes, including climate change, often remains uncertain (UN-Water, 2019).

Water availability and stress

Changes in precipitation and temperature (Figure 8) will directly affect the terrestrial water budget (Schewe et al., 2014). Evaporation from the land surface is expected to increase as a result of the global trend of rising air temperatures in all but the driest regions, where the lack of water prevents such an increase. This increase may be offset by an increase in precipitation, but in many regions and especially in those areas where rainfall volumes will decrease, this leads to decreasing streamflow volumes and a decrease of water availability in different seasons (IPCC, 2018a).

Decreases have already been observed in rivers in western Africa (Batisha, 2012), southwestern Australia (Australian Academy of Science, 2019), the Yellow River basin in China (Piao et al., 2010) and the Pacific Northwest of the United States of America (USA) (Kalra et al., 2008). Such decreases affect water availability directly, for water withdrawal for agriculture, industry and domestic supplies, as well as for in-stream uses such as power generation, navigation, fisheries, recreation and, last but not least, the environment.

The combined impact of changes in precipitation and evaporation will also determine future trends in soil moisture and groundwater, with potential consequences for the frequency and severity of soil moisture drought spells (Van Loon et al., 2016). Increased soil moisture drought has for instance been observed in north-central and northeast Asia (Wang et al., 2011).

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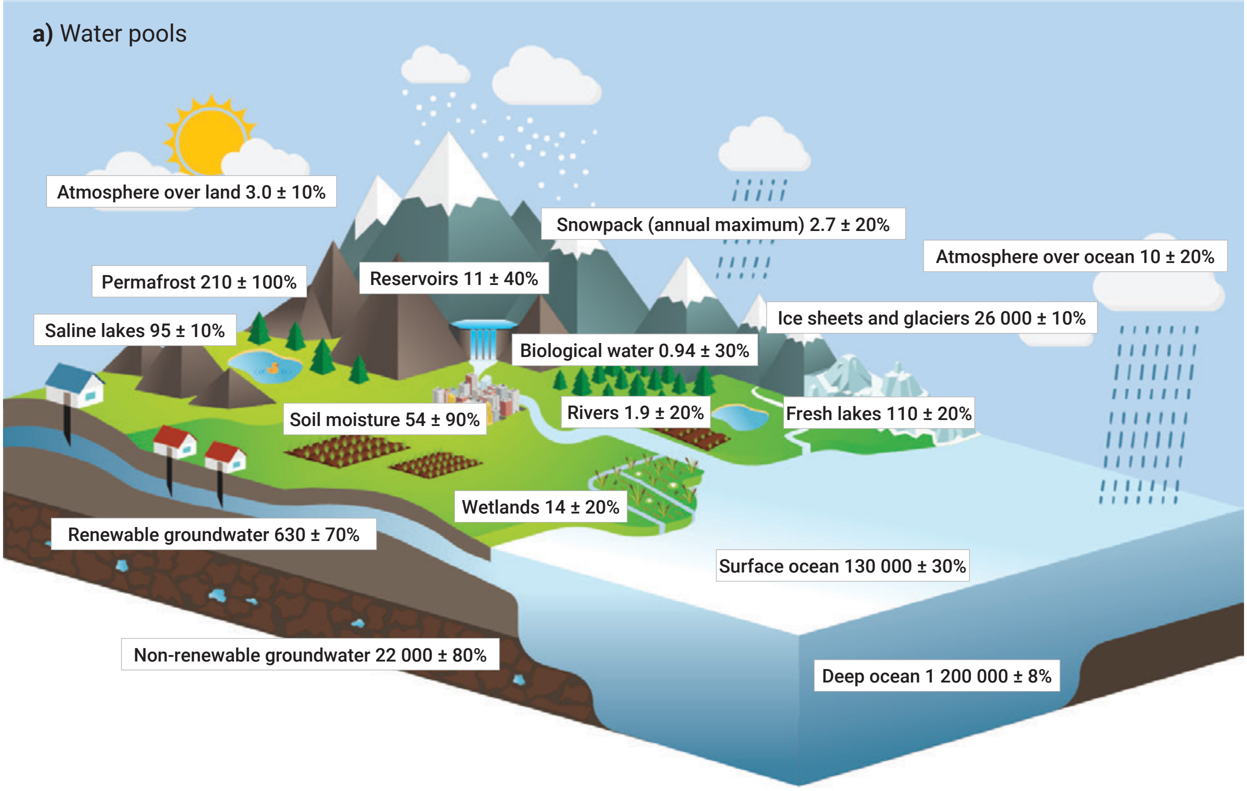
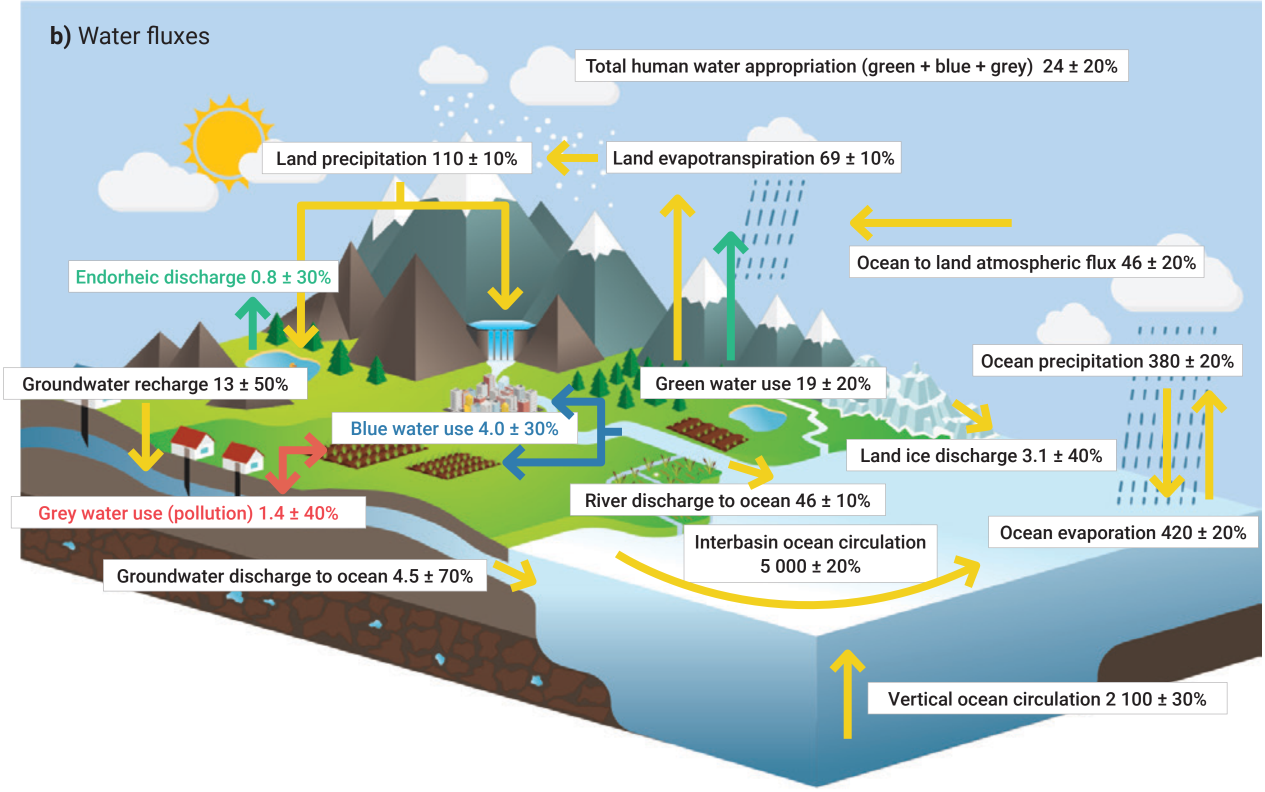
[1] A stationary time series is one whose statistical properties such as mean, variance, autocorrelation, etc. are all constant over time.

Figure 7 Diagram of the global hydrological cycle in the Anthropocene

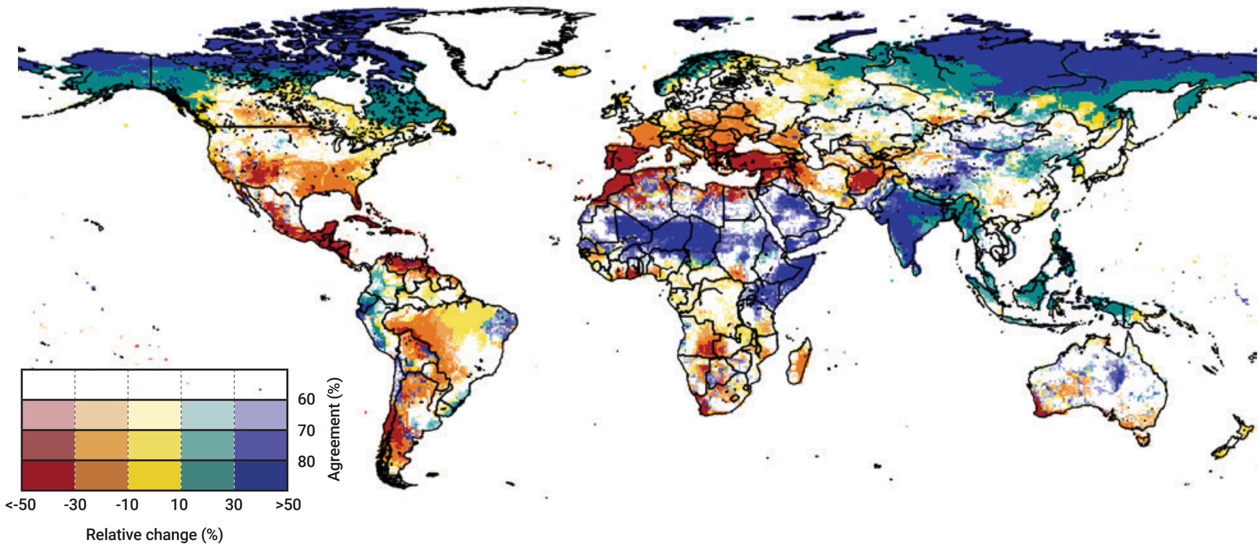

a) Water pools


b) Water fluxes

Note: Major water pools (expressed in 10^3 km^3) (**a**) and water fluxes (expressed in 10^3 km^3 yr^{-1}) (**b**). Uncertainty represents the range of recent estimates expressed in %. In **b**, total human water use (~24 10^3 km^3 yr^{-1}) is separeted into green (soil moisture used by human crops and rangelands, green arrow); blue (consumptive water use by agriculture, industry and domestic activity, blue arrow); and grey (water necessary to dilute human pollutants, which is represented with pink shading, red arrow). This averaged depiction of the hydrological cycle does not represent important seasonal and interannual variation in many pools and fluxes.

Source: Based on Abbott et al. (2019, fig. 3, p. 537).

Figure 8 Climate change scenario trends in water availability



Note: This figure depicts the relative change in annual discharge at 2°C temperature increase compared with present day, under RCP8.5.

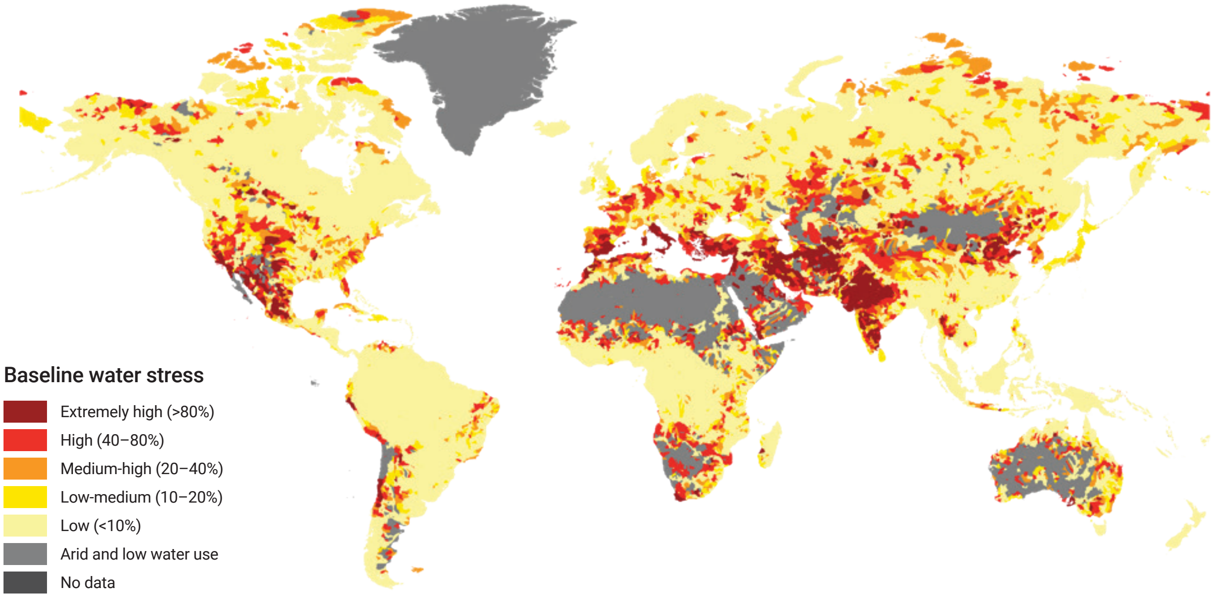
Source: Schewe et al. (2014, fig. 1, p. 3246). The Attribution Share-Alike 3.0 IGO (CC BY-SA 3.0 IGO) licence does not apply to this figure.

Climate change-induced changes in the cryosphere are also widespread, leading to a global reduction in snow and ice cover (Huss et al., 2017). Snow cover, glaciers and permafrost are projected with high confidence to continue declining in almost all regions throughout the 21st century (IPCC, 2019a). Accelerated melting of glaciers is expected to have a negative effect on the water resources of mountain regions and their adjacent lowlands, with tropical mountain regions being among the most vulnerable (Buytaert et al., 2017). Although the accelerated melting of glaciers may locally and temporarily increase streamflow, the reduction of glacier cover tends to lead to more variable river flows and reductions in baseflow in the long term, as well as changes in the seasonal timing of peak streamflow. Shifts to earlier peak flow in snow-dominated rivers have been observed in Eurasian and North American rivers (Tan et al., 2011), while reductions in baseflows in glacier-fed rivers are becoming evident in the Andes and the Himalayas (Immerzeel et al., 2010; Baraer et al., 2015).

Such changes are likely to exacerbate water stress, which is among the main problems to be faced by many societies and the World in the 21st century. Water use has been growing at more than twice the rate of population increase in the last century (FAO, 2013a). Combined with a more erratic and uncertain supply, this will aggravate the situation of currently water-stressed regions, and generate water stress in regions with currently abundant water resources.

Water stress already affects every continent (Figure 9). Physical water scarcity is often a seasonal phenomenon, rather than a chronic one (Figure 10), and climate change is likely to cause shifts in seasonal water availability throughout the year in several places (IPCC, 2014a). About four billion people live under conditions of severe physical water scarcity for at least one month per year (Mekonnen and Hoekstra, 2016). Around 1.6 billion people, or almost a quarter of the world's population, face economic water shortage, which means they lack the necessary infrastructure to access water (UN-Water, 2014).

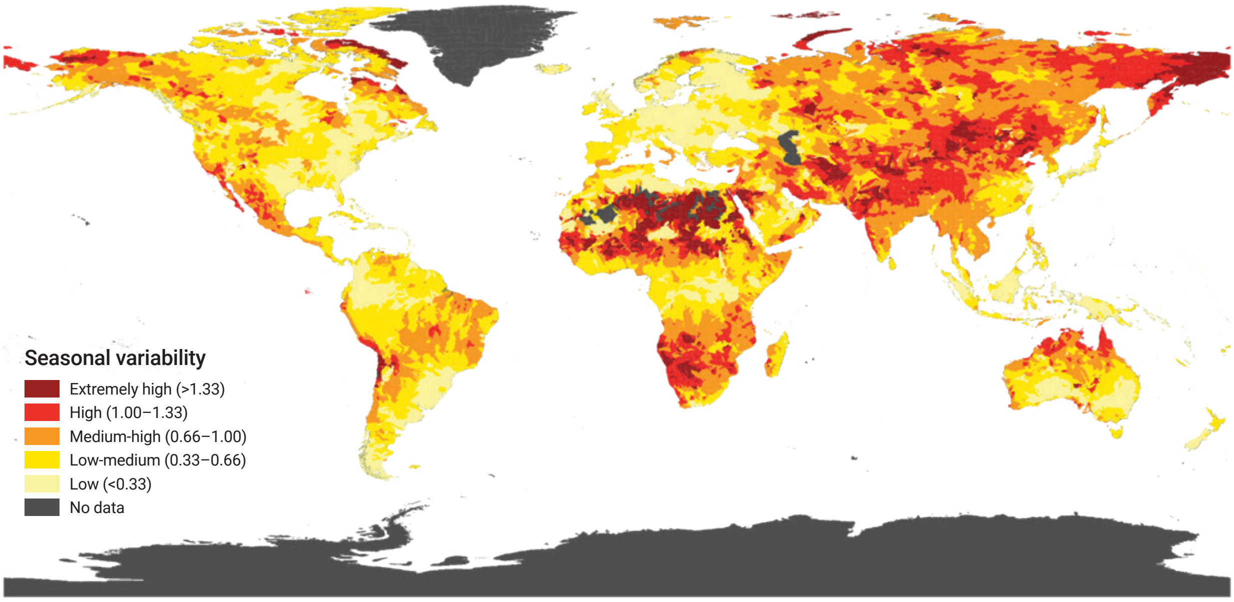
Figure 9 Annual baseline water stress



Note: Baseline water stress measures the ratio of total water withdrawals to available renewable water supplies. Water withdrawals include domestic, industrial, irrigation and livestock consumptive and non-consumptive uses. Available renewable water supplies include surface and groundwater supplies and considers the impact of upstream consumptive water users and large dams on downstream water availability. Higher values indicate more competition among users.

Source: WRI (2019). Attribution 4.0 International (CC BY 4.0).

Figure 10 Seasonal variability



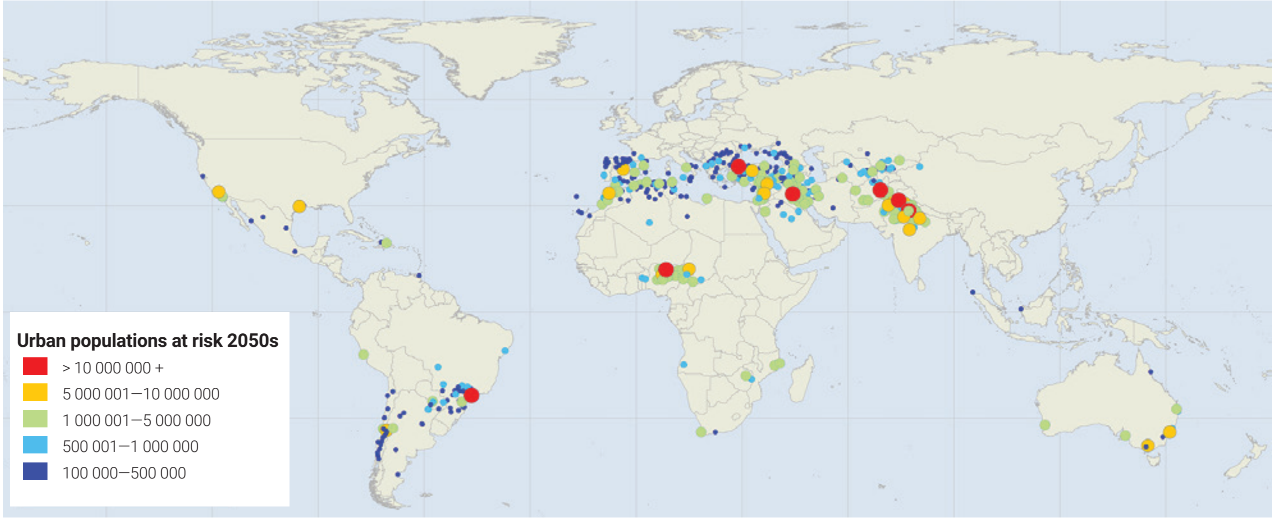
Note: Seasonal variability measures the average within-year variability of available water supply, including both renewable surface and groundwater supplies. Higher values indicate wider variations of available supply within a year.

Source: WRI (2019). Attribution 4.0 International (CC BY 4.0).

Because of the high population density of cities and increasing urbanization, urban water supply is particularly vulnerable. It is estimated that by 2050, 685 million people living in over 570 cities will face an additional decline in freshwater availability of at least 10%, due to climate change (Figure 11). Some cities, such as Amman, Cape Town and Melbourne, can experience declines in freshwater availability by between 30 to 49%, while Santiago may see a decline that exceeds 50% (C40 Cities, 2018).

The societal impact and consequences are likely to be severe. Water scarcity, exacerbated by climate change, could cost some regions up to 6% of their gross domestic product, while spurring migration and sparking conflict (FAO/World Bank Group, 2018).

Figure 11 Decline in urban water availability



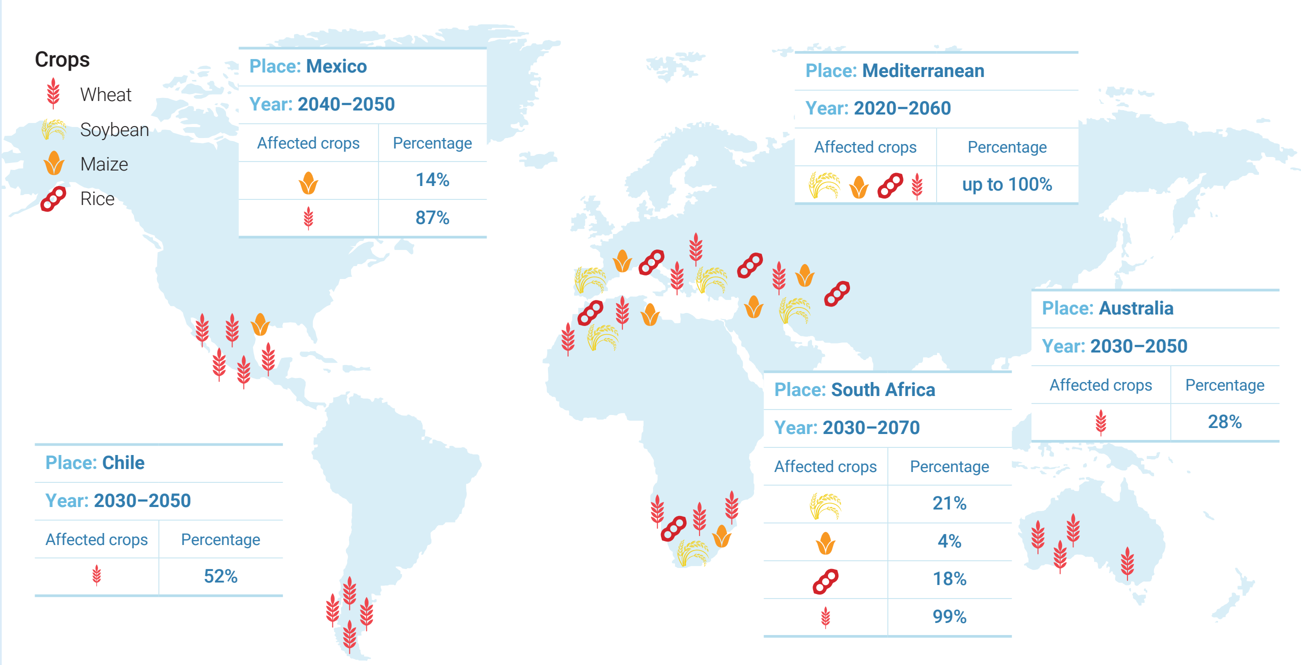
Source: Courtesy of the Climate Impacts Group of the Center for Climate Systems Research at Columbia University, from UCCRN (2018, fig. 5, p. 25).

Knowledge of climate change impacts on agriculture through water has significantly expanded over the past 20 years. Convergent results are showing that climate change will fundamentally alter global food production patterns as a function of water availability. Crop productivity impacts are expected to be negative in low-latitude and tropical regions but somewhat positive in high-latitude regions (FAO, 2015a). By 2040, there will be better rainfall availability for wheat, soybean, rice and maize, even if the Paris Agreement emissions targets are met. Projections show parts of Africa, the Americas, Australia and Europe will be drier, while the tropics and north will be wetter (Figures 12 and 13) (Rojas et al., 2019). Since water mediates much of the climate change impacts on agriculture, increased water scarcity in many regions of the world presents a major challenge for climate adaptation.

Water quality

The world's freshwater resources are increasingly polluted with organic waste, pathogens, fertilizers and pesticides, heavy metals, and emerging pollutants. Water pollution by organic matter is growing because of increasing municipal and industrial wastewater discharge, the intensification of agriculture (including livestock farming) and reduction in river dilution capacity due to decreasing runoff and water extractions (Zandaryaa and Mateo-Sagasta, 2018). Eutrophication is a widespread phenomenon globally because of the release of man-made nutrient enrichments in surface waters as a result of ineffective wastewater and agricultural runoff management. Pathogen contamination is the most widespread water quality problem in developing countries due to unsafe water and sanitation (WHO/UNICEF, 2017). Emerging pollutants present a new global water quality challenge in both developed and developing countries, with potentially serious threats to human health and ecosystems.

Figure 12 Major crops facing drier conditions



Place: Mexico
Year: 2040–2050

Affected crops	Percentage
Maize	14%
Wheat	87%

Place: Mediterranean
Year: 2020–2060

Affected crops	Percentage
Soybean, Maize, Rice, Wheat	up to 100%

Place: Australia
Year: 2030–2050

Affected crops	Percentage
Wheat	28%

Place: South Africa
Year: 2030–2070

Affected crops	Percentage
Soybean	21%
Maize	4%
Rice	18%
Wheat	99%

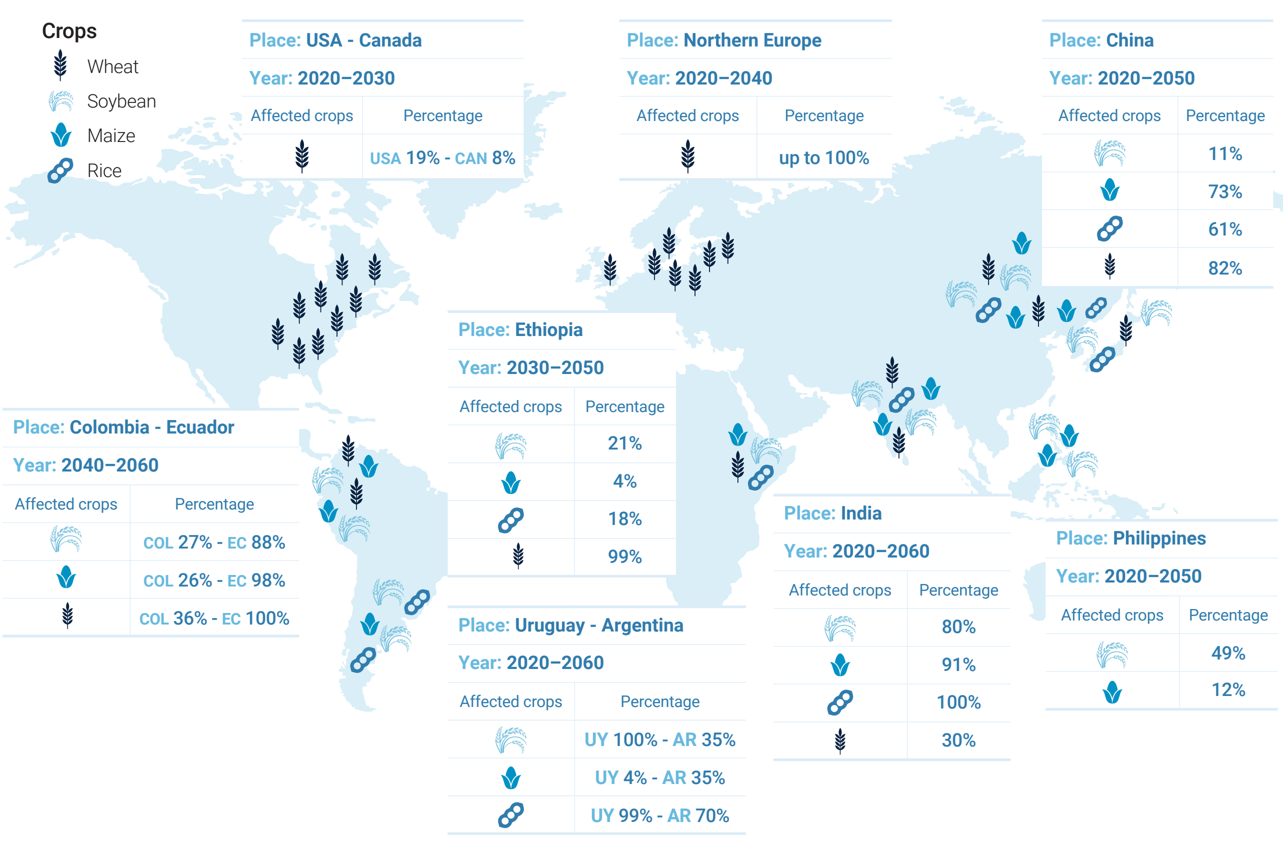
Place: Chile
Year: 2030–2050

Affected crops	Percentage
Wheat	52%

Note: This map shows some countries where portions of land dedicated to major crops – wheat, soybean, rice and maize – will be under permanently drier conditions due to climate change (Rojas et al., 2019). For example, between 2020 and 2060, 28% of land currently dedicated to growing wheat in Australia will receive less precipitation under current trends in greenhouse gas emissions.

Source: Adapted from Anaconas (2019). © 2019 International Center for Tropical Agriculture (CIAT)/by L. Anaconas. Licensed under CC BY-SA 4.0.

Figure 13 Major crops facing wetter conditions



Place: USA - Canada
Year: 2020–2030

Affected crops	Percentage
Wheat	USA 19% - CAN 8%

Place: Northern Europe
Year: 2020–2040

Affected crops	Percentage
Wheat	up to 100%

Place: China
Year: 2020–2050

Affected crops	Percentage
Soybean	11%
Maize	73%
Rice	61%
Wheat	82%

Place: Ethiopia
Year: 2030–2050

Affected crops	Percentage
Soybean	21%
Maize	4%
Rice	18%
Wheat	99%

Place: Colombia - Ecuador
Year: 2040–2060

Affected crops	Percentage
Soybean	COL 27% - EC 88%
Maize	COL 26% - EC 98%
Wheat	COL 36% - EC 100%

Place: India
Year: 2020–2060

Affected crops	Percentage
Soybean	80%
Maize	91%
Rice	100%
Wheat	30%

Place: Philippines
Year: 2020–2050

Affected crops	Percentage
Soybean	49%
Maize	12%

Place: Uruguay - Argentina
Year: 2020–2060

Affected crops	Percentage
Soybean	UY 100% - AR 35%
Maize	UY 4% - AR 35%
Rice	UY 99% - AR 70%

Note: This map shows some countries where portions of land dedicated to major crops – wheat, soybean, rice and maize – will be under permanently wetter conditions due to climate change (Rojas et al. 2019). For example, between 2020 and 2060, 82% of land currently dedicated to wheat cultivation in China will receive more precipitation under present trends in greenhouse gas emissions.

Source: Adapted from Anaconas (2019). © 2019 International Center for Tropical Agriculture (CIAT)/by L. Anaconas. Licensed under CC BY-SA 4.0.

Climate-induced harmful algae blooms (HABs) are increasing due to warmer water temperatures caused by global warming. Many lakes and estuaries around the world, which provide drinking water for millions of people and support ecosystem services, already have toxic, food web-altering, hypoxia-generating blooms of harmful cyanobacteria. For example, in China, more than 60% of the lakes suffer from eutrophication and HABs (Shao et al., 2014). Climate change is severely affecting our ability to control these HABs, or making it near impossible (Havens and Paerl, 2015).

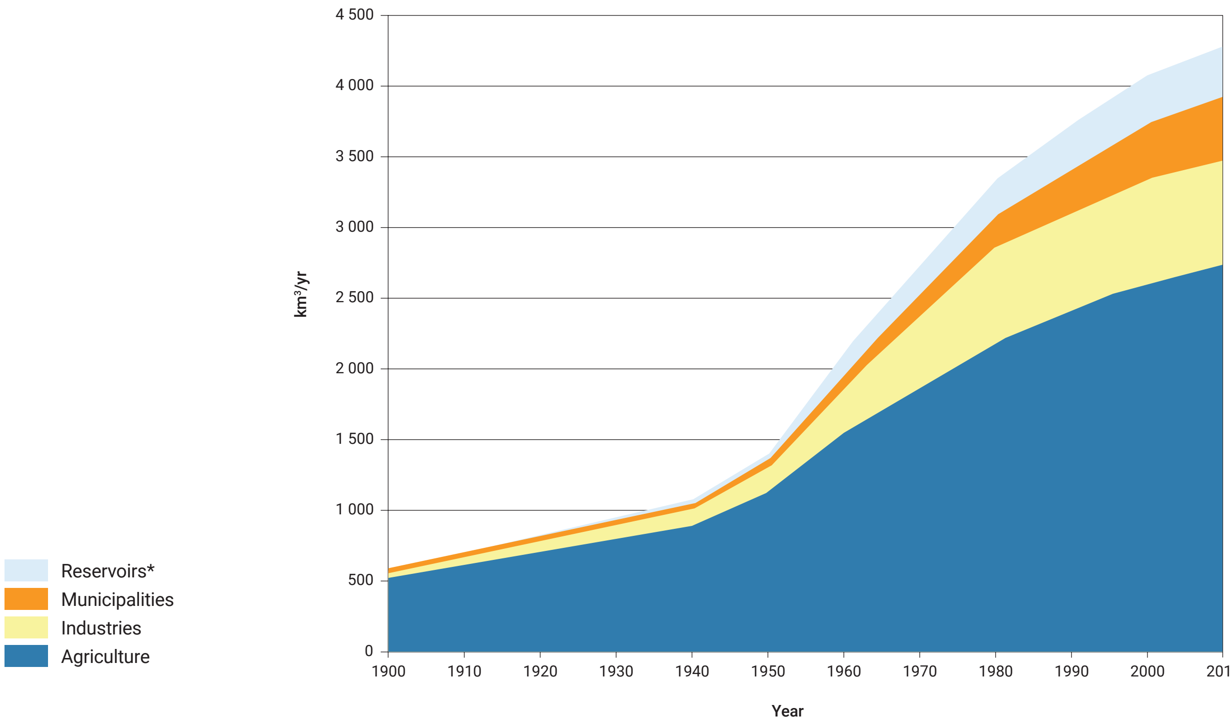
Global water use has increased by a factor of six over the past 100 years

Freshwater and coastal wetlands are already adversely affected by human impacts, such as altered flow regimes and deterioration of water quality. Climate change is likely to further stress the world's wetlands and aquatic ecosystems with negative implications on fisheries and aquaculture (Poff et al., 2002). These changes in water quality not only affect the economic and social welfare but also the sustainability of vital environmental flows, ecosystems and biodiversity (WWAP, 2017).

Water demand

Global water use has increased by a factor of six over the past 100 years (Figure 14) and continues to grow steadily at a rate of about 1% per year (AQUASTAT, n.d.) with increasing population, economic development and shifting consumption patterns. In 2012, the Organisation for Economic Co-operation and Development (OECD) projected that water demand would increase by 55% globally between 2000 and 2050, mainly as a function of growing demands from manufacturing (+400%), thermal power generation (+140%) and domestic use (+130%) (OECD, 2012). A different study concluded that the world could face a 40% global water deficit by 2030 under a business-as-usual scenario (2030 WRG, 2009).

Figure 14 Global water withdrawals throughout the previous century



Note: *Evaporation from artificial lakes.

Source: AQUASTAT (2010).

In the face of these competing demands, there will be little scope for increasing the amount of water used for irrigation, which currently accounts for 69% of all freshwater withdrawals (AQUASTAT, n.d.). While the OECD projects an overall decrease in future global water withdrawals for irrigation, the Food and Agriculture Organization of the United Nations (FAO) estimated a 5.5% increase in irrigation water withdrawals from 2008 to 2050 (FAO, 2011a). Discrepancies in such projections highlight the challenge of projecting the growth in water demand at the global scale. However, "*regardless of the magnitude of future global, and more importantly local, water deficits, water scarcity is likely to limit opportunities for economic growth and the creation of decent jobs in the coming decades*." (WWAP, 2016, p. 23).

Global warming will further exacerbate this trend, as water demand tends to increase with temperature (Gato et al., 2007). This will exert significant pressure on the water authorities to maintain the balance between water demand and supply. Therefore, assessing the climate change impacts on water demand is crucial to ensure water demand is met under changed climate conditions. Temperature and rainfall are the most commonly used climate variables in water demand modelling (Haque et al., 2015).

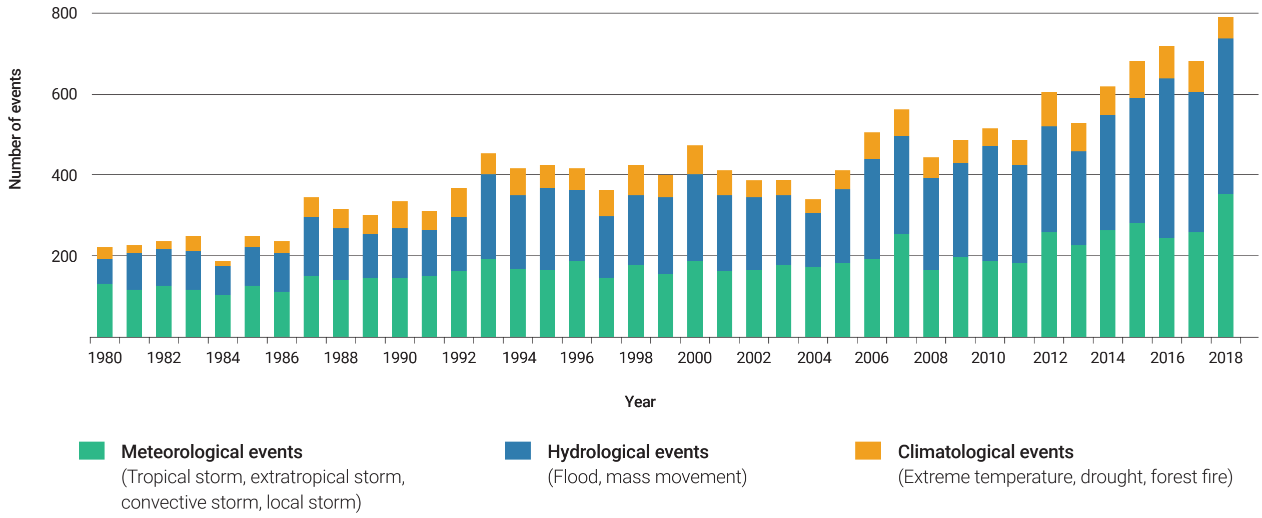
The combined effects of growing populations, rising incomes, changing consumption patterns and expanding cities will see demand for water rise significantly, combined with a more erratic and uncertain supply. This may generate water stress in regions with currently abundant water resources, such as Central Africa and East Asia (World Bank, 2016a).

Water-related disasters and extreme events

Changes in precipitation patterns under climate change conditions are expected to increase the intensity and frequency of flood and drought events in many regions (Hirabayashi et al., 2013; Asadieh and Krakauer, 2017). Such changes may also lead to secondary effects. For example, combined with changes in vegetation, they will also lead to the destabilization of slopes and thus higher potential for sudden floods and landslides (Gariano and Guzzetti, 2016).

Global floods and extreme rainfall events have surged by more than 50% this decade, and are now occurring at a rate four times higher than in 1980. Other extreme climatological events such as storms, droughts and heatwaves have increased by more than a third this decade and are being recorded twice as frequently as in 1980 (EASAC, 2018). Figure 15 shows the increasing trends in flood-related disasters globally, as well as meteorological and climatological events.

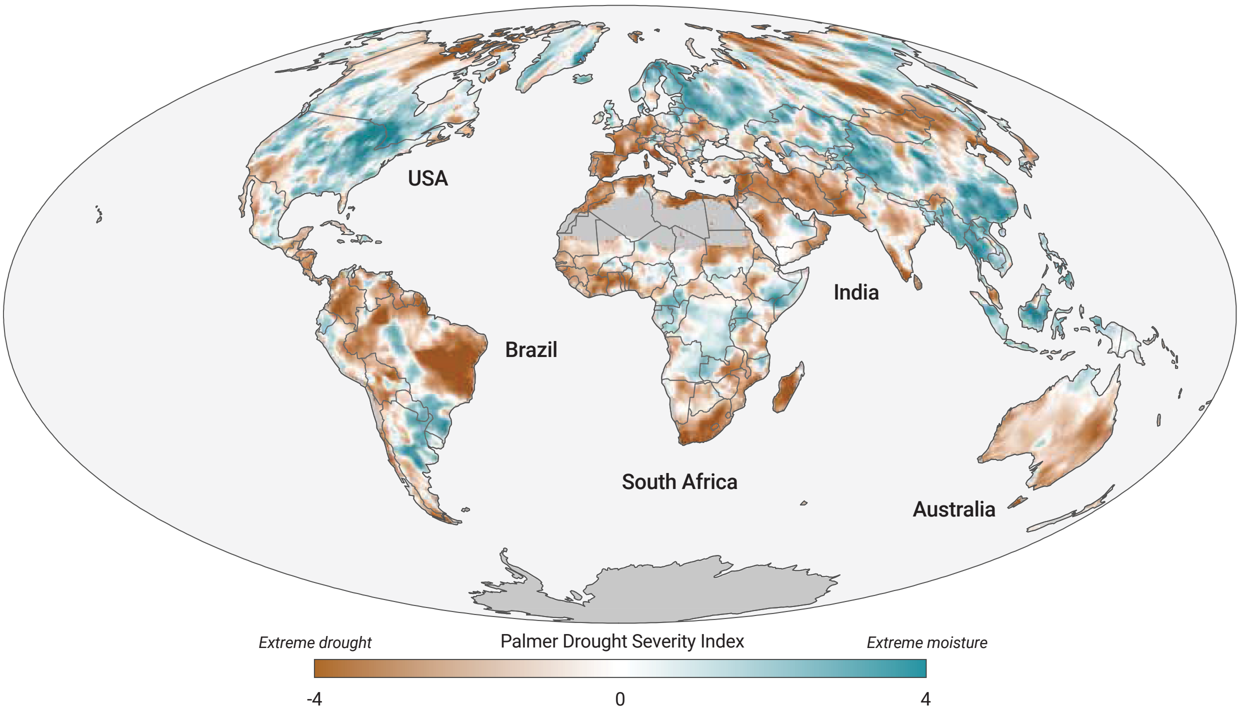
Figure 15 World weather-related natural catastrophes by peril, 1980–2018



Note: Accounted events have caused at least one fatality and/or produced normalized losses ≥ US$100K, 300K, 1M, or 3M (depending on the assigned World Bank income group of the affected country).

Source: MunichRe, NatCatSERVICE (2019).

Figure 16 Global Drought Severity Index, 2017



Note: Dry conditions appear in shades of brown, and wet conditions appear in shades of blue-green. The darker the colour, the greater the intensity of wet or dry conditions, with near-normal conditions nearly white.

Source: Scott and Lindsey (2018), based on Blunden et al. (2018, fig. 2.32, p. S37).

During the past 20 years, the two main water-related disasters – floods and droughts – caused more than 166,000 deaths, affected another three billion people and caused total economic damage of almost US$700 billion (EM-DAT, 2019). Droughts accounted for 5% of natural disasters, affecting 1.1 billion people, killing 22,000 more, and causing US$100 billion in damage over the 20-year period (1995–2015). Over the course of one decade, the number of floods rose from an annual average of 127 in 1995 to 171 in 2004 (CRED/UNISDR, 2015).

Figure 16 shows global drought patterns in 2017 based on the Palmer Drought Severity Index, which uses regional temperature and precipitation data to estimate dryness. Global-scale drought conditions temporarily improved in early 2017 compared to recent years. The area of global droughts reached its highest level in several years starting in late 2015 and remained high throughout 2016, but rapidly declined by early 2017.

Water-related ecosystems

Water-related ecosystems such as lakes, rivers and vegetated wetlands are among the world's most biologically diverse environments and provide multiple benefits and services to society, making them essential for reaching several Sustainable Development Goals (SDGs) (WWAP/UN-Water, 2018). Although they account for only 0.01% of the world's water and cover approximately 0.8% of the Earth's surface, they provide a habitat for almost 10% of the world's known species. In arid environments, springs host over half the species (UN Environment/ UN-Water, 2018). Additionally, water-related ecosystems have significant economic, cultural, aesthetic, recreational and educational value. They help to sustain the global hydrological, carbon and nutrient cycles. They support water security, provide natural freshwater, regulate flows and extreme conditions, purify water, and replenish aquifers. Other services also depend on these ecosystems, which provide water for drinking, agriculture, employment, energy generation, navigation, recreation and tourism. Moreover, water services go beyond water supply to humans: water also supports plants and animals, which themselves provide services to humans: biodiversity, food, energy, tourism, green infrastructure, etc.

Many of these ecosystems, particularly forests and wetlands, are at risk, and with them their water-related ecosystem services. Changes in water flows through river systems and/or from coastal storm surges threaten to destroy many wetlands, which would cause the loss of the filtering, buffering and carbon sequestration services they currently provide. Human activities (such as dam construction and cultivation of wetlands and forests) also place high pressure on ecosystems (Blumenfeld et al., 2009). Hot, dry conditions will increase the risk of wildfires in all types of forest, while warmer and longer growing seasons in mountain forests could lead to an explosion of pest populations.

Wetlands are also huge carbon pools. Peatlands alone store twice as much carbon as the Earth's forests. Healthy wetlands function as carbon sinks, degraded wetlands are significant sources of GHGs. The extent of wetlands has sharply declined (35%) between 1970 and 2015 (Crump, 2017).

The current state of the world's water-related ecosystems, of which the majority is already degraded and polluted, is alarming. Over the past 100 years, the world is estimated to have lost half its natural wetlands and with this a significant number of freshwater species (UN Environment/UN-Water, 2018).

Around one in ten known species of plants, mammals, fishes, reptiles, insects and mollusks, amounting to more than 126,000 species, live in freshwater ecosystems, even though these cover less than 1% of the Earth's surface. Around 880 of those species show an 83% decline according to the Freshwater Living Planet Index. The regions most at risk are the Neotropics (-94%), the Indo-Pacific (-82%), and the Afrotropics (-75%), with reptiles, amphibians and fishes being most vulnerable (WWF, 2018). In the 20th century, freshwater fish have had the highest extinction rate worldwide among vertebrates.

Increasing water temperature will also alter biogeochemical balances in freshwater ecosystems, which may lead to deterioration of water quality, for instance because of more frequent algae blooms, and faster growth of pathogens (Chapra et al., 2017).

Water infrastructure

Projections of the needs for water security investment diverge, but they all indicate that the scale of investment ought to increase significantly (see Chapter 12). Global estimates range from US$6.7 trillion by 2030 to US$22.6 trillion by 2050 (WWC/OECD, 2015). To achieve the WASH component of SDG 6 by 2030, it is estimated that capital investment needs to triple (to reach US$1.7 trillion), and operating and maintenance costs will be commensurately higher (Hutton and Varughese, 2016). The FAO has projected that an estimated US$960 billion of capital investment is needed to expand and improve irrigation until 2050 in 93 developing countries, compared to the 2005–2007 levels of investment (Koohafkan, 2011).

Climate change generates additional risks to water-related infrastructure, requiring an ever-increasing focus on the inclusion of adaptation measures

Investments are needed not only in new infrastructure but also in the maintenance and operations of the existing stock, in order to improve their efficiency and reduce water losses. Climate change generates additional risks to water-related infrastructure, requiring an ever-increasing focus on the inclusion of adaptation measures.

Investment will need to be channelled into creating the appropriate water infrastructure in developing countries, and targeted at upgrading existing infrastructure in advanced economies. Many developed countries are dependent on ageing infrastructure, designed and constructed on the assumption of stationary hydrological time series, and many water networks are nearing the end of their design lives. For example, in the United Kingdom, 75% of the urban water networks are more than 100 years old (Water UK, 2011).

Risk-sensitive areas – SIDS, semi-arid regions, coastal hinterlands and mountainous areas

Small Island Developing States

Small Island Developing States (SIDS) are typically characterized as environmentally and socio-economically vulnerable to disasters and climate change. They also often have limited resources for freshwater provisioning services. The number of disasters in SIDS is increasing at a higher rate than the global average, and the frequency and intensity of the disasters will likely increase because of climate change (Gheuens et al., 2019). These combined factors will impact SIDS on the societal level and on environmental levels, reducing their adaptive capacity, resources and resilience. Sea level rise is a major concern for many low-lying islands: the seawater/freshwater interface will move inland and decrease the volumes of groundwater available (UNESCO-IHP/UNEP, 2016). Because of increasing demand (e.g. population growth and tourism) and decreasing supply (e.g. pollution and changes in precipitation patterns), freshwater resources are becoming increasingly limited, often suffering from the spill-over effects of competing and conflicting uses. Threatened ecosystems and limited economic resources further influence the adaptive capacities of communities in SIDS (Gheuens et al., 2019).

Studies predict that water scarcity will continue to increase in the future, with around 52% of the world's population living in water-stressed regions by 2050 (Kölbel et al., 2018). SIDS will be particularly affected by this trend because of their vulnerabilities and already scarce freshwater resources. Most SIDS will experience a decrease in freshwater supply as a result of decreased rainfall and an increase in demand, triggered by growth in population and tourism. Tuvalu, for example, has already had problems with water supply in 2011 when it had no rain for six months, and 1,500 of its population of 11,000 were left with no access to freshwater (Gheuens et al., 2019).

Semi-arid regions

Climate change impacts add to already difficult water management challenges in the arid and semi-arid regions (drylands) (WWC, 2009). Drylands are ecosystems, such as rangelands, grasslands and woodlands, characterized by high temporal and spatial rainfall variability. They are commonly defined as regions in which the annual potential evapotranspiration (PET) greatly exceeds annual precipitation (P); that is, the P/PET ratio is less than 0.65 (Huang et al., 2017).

Huang et al. (2017) have shown that climate change is the main contributor to the long-term trend in the Aridity Index. The increasing aridity, enhanced warming and rapidly growing population will exacerbate the risk of land degradation and desertification in the near future, with as much as 80% of this expansion occurring in developing countries.

About 20–35% of drylands already suffer some form of land degradation, and this is expected to expand significantly under different emissions scenarios (IUCN, 2018). Land degradation impairs water security through a reduction in the reliability, quantity and quality of water flows (IPBES, 2018).

Climate models project decreasing precipitation in already dry areas, such as northern Africa. In South Asia, earlier snowmelt and the loss of glacial buffering in the Hindu Kush–Himalayas will affect the seasonal water supply for a significant proportion of the population of the subcontinent and change the frequency and severity of extremes (WWC, 2009).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) recommends timely action to avoid, reduce and reverse land degradation with the aim of increasing food and water security. It also notes that while intensified land management systems have greatly increased crop and livestock yields in many areas of the world, when inappropriately managed, they can result in high levels of land degradation, including soil erosion, fertility loss, excessive ground and surface water extraction, salinization, and eutrophication of aquatic systems (IPBES, 2018).

Coastal hinterlands

Coastal areas are vulnerable from the increase in sea levels, flooding, storm surges and stronger winds. More than 600 million people (around 10% of the world's population) live in coastal areas that are less than ten meters above sea level (McGranahan, et al., 2007) and these areas are becoming increasingly urbanized. During this century, flooding from the rising sea level and storm surges will threaten the viability of some islands as well as some major deltas, such as the Nile and Mekong River deltas (WWC, 2009). In addition to direct impacts, this will also have severe impacts on water supply and sanitation infrastructure.

Mountainous areas

There is growing evidence that high-mountain areas are warming faster than lower elevations (Pepin et al., 2015). This elevation-enhanced acceleration in warming makes mountainous areas exceptionally vulnerable to climate change. This is most obvious from the impact on mountain glaciers and snowcaps, which show a decreasing trend almost everywhere in the world (Figure 17) (Huss et al., 2017), affecting water resources for downstream populations (Immerzeel et al., 2019). Although the way in which meltwater contributes to downstream water availability is complex (Buytaert et al., 2017), glacier and snowmelt water increases water security in many parts of the world. Glacier meltwater is a particularly important buffer against drought in arid and semi-arid mountain bases such as the upper Indus, Aral and Chu/Issyk-Kul River basins (Pritchard, 2019). Current trends in cryosphere-related changes in high-mountain ecosystems are expected to continue and impacts to intensify. The amount and seasonality of river runoff in snow-dominated and glacier-fed river basins will change further in response to projected snow cover and glacier decline with potentially negative impacts on agriculture, hydropower and water quality (IPCC, 2019a).

At the same time, climate change impacts in mountain regions extend beyond the acceleration of glacier melt and the reduction of snowcaps, but will also lead to changes in vegetation, soils and non-glacier-related hydrological processes (Tovar et al., 2013). These changes affect a large range of ecosystem services, including water availability but also biodiversity, soil fertility and carbon sequestration (Buytaert et al., 2011).

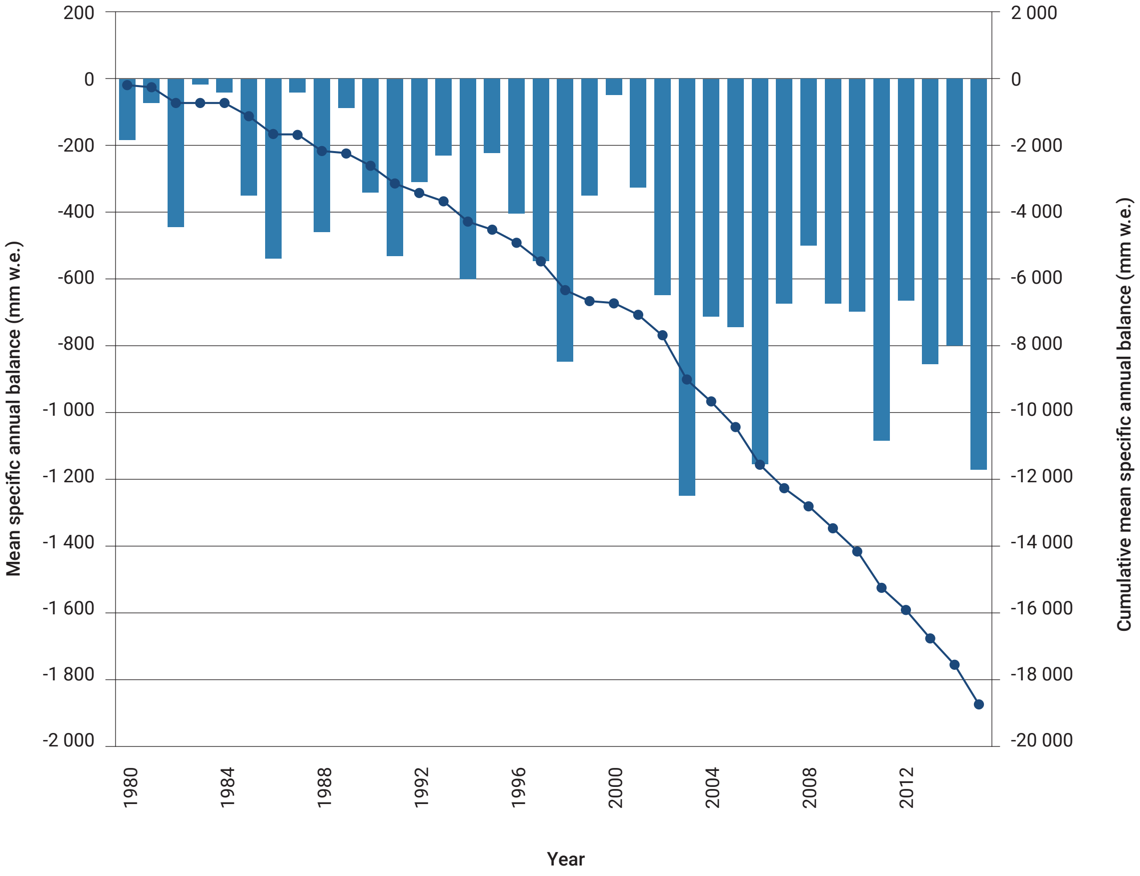
Limitations and challenges

As identified by the IPCC (2014a; 2018a), a wide range of limitations remains before the potential impacts of a changing climate on water resources are fully understood. While there is not much disagreement in temperature increases simulated by different GCMs under specific scenario conditions, more variability and uncertainty exist in projected precipitation trends (IPCC, 2014a). By far the greatest limitation is the uncertainty in the projection of the predicted climate changes into the complex interactions between atmosphere, land and oceans and consequently, the water resources.

Yet as described above, evidence is emerging globally that the climate is changing beyond the natural variability and that this affects the availability and the temporal and spatial distribution of water resources. One study by Hattermann et al. (2018) suggests that small increases in global temperature can have statistically significant impacts on river discharge, but this effect is often concealed by the uncertainty in precipitation trends projected by GCMs. Temperature increases are generally expected to intensify the hydrological cycle (Kundzewicz and Schellnhuber, 2004), but the feedback with different climate variables, such as evapotranspiration fluxes, is nonlinear.

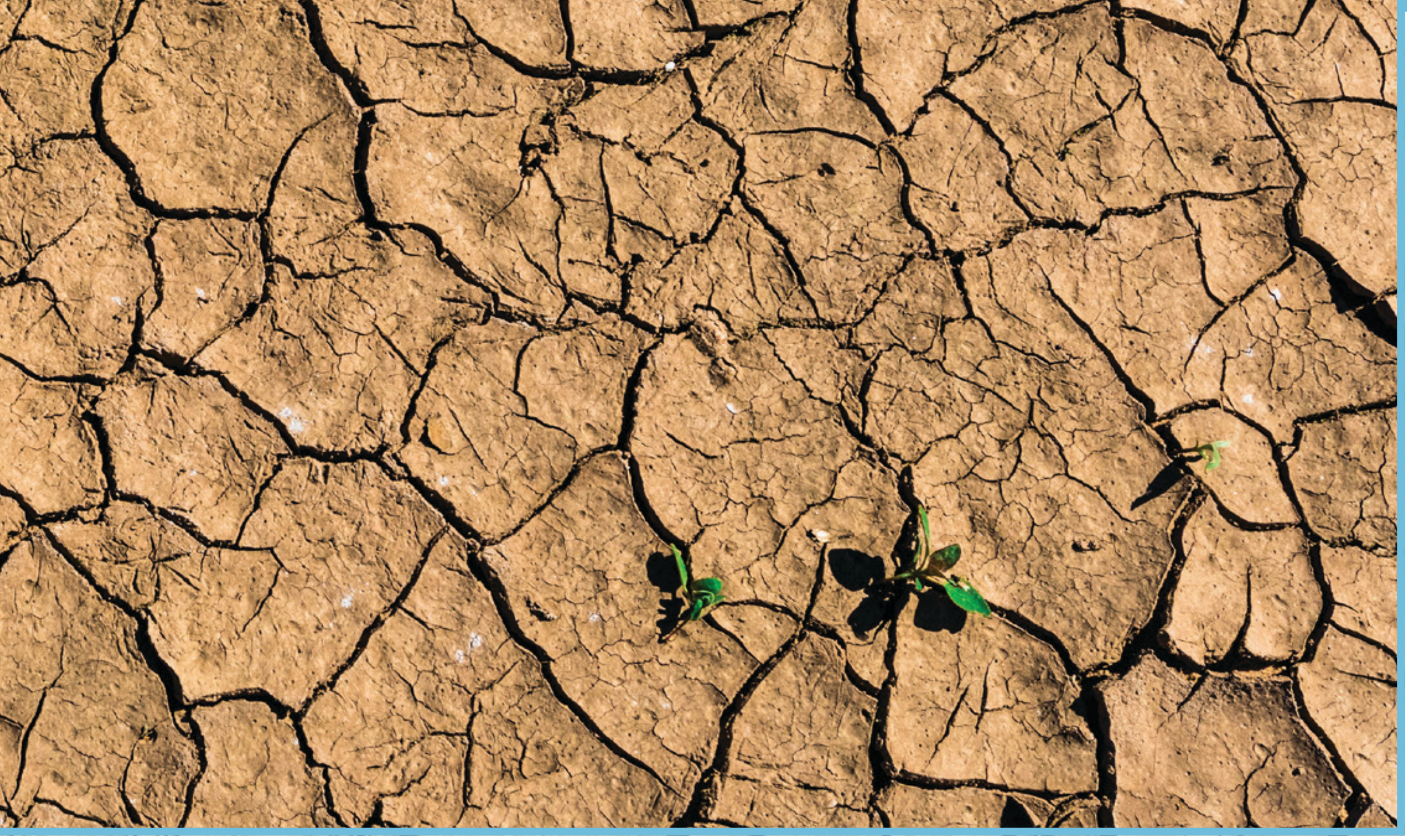
The fact that strong impacts on water resources and extremes will occur is often obscured by large climate model-related uncertainty, especially in the transition zones between regions with increasing and decreasing annual precipitation. Often, trends in extremes (heavier precipitation, heat, prolonged droughts) show a clearer direction than trends in annual precipitation totals. Hydrological modelling adds another layer of uncertainty. Using regional models considering catchment-specific characteristics can decrease the uncertainties in the hydrological model (GIZ/adelphi/PIK, forthcoming).

Figure 17 Mass balance evolution of 41 reference glaciers monitored by the World Glacier Monitoring Service



Note: Mass balance is expressed in mm of water equivalent (w.e.). The bars indicate mean annual glacier balance, and the line indicates cumulative annual balance.

Source: Pelto (2016, fig. 2.13, p. S23).



Although current and historic trends become increasingly clear and statistically significant, making accurate predictions for the future remains challenging. A number of studies (for example, Görgen et al. (2010) on the Rhine River basin and Elshamy et al. (2009) on the Nile River basin) have used downscaling of climate change scenarios and hydrological modelling to predict the possible impacts of climate change on river flows. In some instances, predicted reductions in summer discharges are up to 25% whilst winter discharges may increase by up to 15%. Both studies however highlight the challenges and limitations of such downscaling approaches. While downscaling produces climatic information at scales finer than the initial projections, this process involves additional information, data and assumptions, leading to further uncertainties and limitations of the results (USAID, 2014).

Although methods to quantify the contribution of climate change to particular extreme weather events (floods and droughts) or other events are developing rapidly, there is as yet no consensus on which approach is best. Attribution depends fundamentally on global climate models that can adequately capture regional weather phenomena – including circulation anomalies. Any statement on attribution should therefore always be accompanied by a scientifically robust demonstration of the model's ability to simulate the global and regional weather patterns and the related weather phenomena that lie at the root of extreme events (NAS, 2016).

Lastly, making a global assessment of the status of water resources and water-related risks has become more challenging because of the need to increase the evidence base to support planning and decision-making. In its *Assessment of the State of Hydrological Services in Developing Countries*, the World Bank Group (2018a) states that only 10% of countries surveyed had adequate water-related monitoring systems, while 80% of the countries surveyed did not have adequate water-related information being collected to meet user needs. Increasing the global hydrological monitoring and data collection activities therefore remains a major challenge. In addition to strengthening global monitoring networks, this may require exploring the potential of new technologies (Tauro et al., 2018), as well as new approaches such as participatory monitoring and citizen science (Buytaert et al., 2014).

1

Climate change, water and sustainable development

Grey heron in the rice fields of the natural park of Albufera (Valencia, Spain).

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This introductory chapter describes the objectives and scope of the report, describing the main concepts related to water and climate, emphasizing the cross-sectoral nature of the challenges and potential responses, and highlighting those that are potentially the most vulnerable.

1.1 Objectives and scope

The scientific evidence is clear: the climate is changing and will continue to change (IPCC, 2018a), affecting societies and the environment. This occurs directly through changes in the hydrological systems that are affecting water availability, water quality and extreme events, and indirectly through changes in water demand, which in turn can have impacts on energy production, food security and the economy, among others. Climate change will influence the spread of water-related diseases and will affect the attainment of a number of other Sustainable Development Goals (SDGs) (World Bank, 2016a). This in turn will both lead to additional security risks and limit the available opportunities for development (PBL Netherlands Environmental Assessment Agency, 2018).

Population growth, economic development, changing consumption patterns, intensified agricultural production and expanding cities will generate a substantial rise in water demand (Wada and Bierkens, 2014), while water availability becomes more erratic and uncertain (UNU-INWEH/UNESCAP, 2013; FAO, 2017a; IPCC, 2018a). Water supply and sanitation services, including water and wastewater treatment facilities, can be highly vulnerable to potential shifts in hydro-climatic parameters. Climate-related risks to health, livelihoods, food and energy security, human security, and economic growth, which are projected to increase with a global warming of 1.5°C, would increase further at a 2°C level, meaning that the SDGs are more easily achieved by limiting warming to 1.5°C (IPCC, 2018a). As such, climate change directly and indirectly threatens human rights (HRC, 2018). The rising incidence of weather extremes, such as floods and storms, not only increases the direct risk of drowning, injury, or damage to human settlements, but also the indirect consequences such as the spread of waterborne diseases (Watts et al., 2018).

The energy and agriculture sectors are increasingly shifting to low-emissions production systems, with generally positive implications for freshwater demand as well as water pollution. However, the quality of water resources is expected to deteriorate due to a number of interacting factors: increased temperature; increased sediment, nutrient, and pollutant loadings from heavy rainfall; increased concentration of pollutants during droughts; disruption of treatment facilities during floods; and groundwater deterioration due to saline intrusion in coastal areas as a consequence of sea level rise (IPCC, 2014a; UNEP, 2016). Companies are increasingly encountering disruption of their operations due to problems of water supply and water quality, as well as floods and droughts (Newborne and Dalton, 2016). Furthermore, the degradation of ecosystems will not only lead to biodiversity loss, but also affect the provision of water-related ecosystem services, such as water purification, carbon capture and storage, and natural flood protection, as well as the provision of water for agriculture, fisheries and recreation. These developments particularly affect people who depend on natural resources for their lives and livelihoods (PBL Netherlands Environmental Assessment Agency, 2018). Meeting the increasing demand for freshwater to satisfy basic human needs, while at the same time protecting ecosystems, will require concerted efforts among all stakeholders to find a sustainable balance between social, economic and ecological needs (Timmerman et al., 2017).

With mounting evidence of the ongoing meteorological and hydrological changes (Blöschl et al., 2017; Su et al., 2018) and projections of substantial increases of these changes in the near future, the urgency of adaptation in water management is unquestionable. Without concrete adaptation measures, water scarcity, both in terms of surface water and groundwater resources, is expected to expand to some regions where it currently does not exist and to considerably worsen in many regions where water resources are already stressed (Gosling and Arnell, 2016).

Beyond the uptake of urgently needed adaptation measures to increase water system resilience, improved water management opens up opportunities for climate change mitigation as well as adaptation. Mitigation measures such as water reuse, conservation agriculture and renewable energies (hydropower, biofuels, wind, solar, and geothermal) can directly affect water resources (for example, by increasing or decreasing water demand), and it is important to recognize this two-way relationship when developing and evaluating mitigation options (Wallis et al., 2014).

Adaptation and mitigation are complementary strategies for managing and reducing the risks of climate change. Substantial greenhouse gas (GHG) emission reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term, and contribute to climate-resilient pathways for sustainable development (IPCC, 2018a).

Adaptation and mitigation are complementary strategies for managing and reducing the risks of climate change

Adaptation options exist in all water-related sectors and should be investigated and exploited where possible. Mitigation options are also available across a variety of water management interventions. While adaptation and mitigation are activities, resilience is a property of a system. Adaptation, as well as certain mitigation measures (for example via carbon capture and storage through forest restoration), can increase or decrease resilience (Box 1.1). This report aims at improving the understanding of what works best, where, and under which circumstances, also taking into account (potential) co-benefits, synergies and trade-offs. Adaptation as discussed in this report is a combination of natural, engineered and technological options, as well as social and institutional measures, where all measures should emphasize flexibility, knowledge and learning (IPCC, 2014a; 2014b; WWAP, 2015).

Box 1.1 Definitions

Adaptation[1] in this report is defined as the process of adjustment in/to natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2014b; UNFCCC, n.d.a).

Mitigation is defined as a human intervention to reduce the sources or enhance the sinks of greenhouse gases as well as other substances. It may contribute directly or indirectly to limiting climate change, including for example through the reduction of particulate matter emissions that can directly alter the radiation balance (e.g. black carbon) or through measures that control emissions of carbon monoxide, nitrogen oxides, volatile organic compounds and other pollutants that can alter the concentration of the tropospheric ozone, which has an indirect effect on the climate (IPCC, 2014b; UNFCCC, n.d.a).

Resilience is defined as the ability of social, economic and environmental systems exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions, while also maintaining the capacity for adaptation, learning and transformation (IPCC, 2014b; UNDRR, n.d.).

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[1] Alternative definition: Climate adaptation refers to the actions taken to manage impacts of climate change by reducing vulnerability and exposure to its harmful effects and exploiting any potential benefits (IPCC, 2018b, p. 31).

It should be noted that the effects of mitigation occur on different time and spatial scales than the effects of adaptation. As a result of the inertia of the climatic system, mitigation measures will only have an effect at time scales of several decades and over wide areas. Adaptation options, on the other hand, can have an almost immediate effect in reducing vulnerability in a specific locality or region, and should therefore be considered at the different time scales they target. Adaptation measures can be taken to address short-term changes (up to 10 years), changes at medium term (10 to 30 years) or changes expected over the long term (30 years and more).

Water-related adaptation options exist in all sectors, but their context for implementation and their potential to reduce climate-related risks differ across sectors and regions. Some adaptation responses involve significant co-benefits, synergies and trade-offs. Increasing climate change will augment the challenges for many adaptation options (IPCC, 2014c).

Mitigation options are available in every major water-related sector. Mitigation can be more cost-effective if an integrated approach is used that combines measures to reduce energy use and the GHG intensity of end-use sectors, decarbonize energy supply, reduce net emissions, and enhance carbon sinks in land-based sectors (IPCC, 2014c). Like adaptation, water-related mitigation options also offer a number of economic, social and environmental co-benefits (see Chapter 9).

This report addresses the critical linkages between water and climate change in the context of the broader sustainable development agenda. It focuses on the challenges, opportunities and potential responses to climate change – in terms of adaptation, mitigation and improved resilience – that can be addressed by enhancing water resources management, attenuating water-related risks, and improving access to water supply and sanitation services for all in a sustainable manner. Since many aspects of climate impacts are uncertain (and noting that there may well be unintended benefits), integrated solutions should be robust (spanning a wide range of potential futures) and flexible (capable of responding to unexpected or alternative futures) (SIWI, n.d.). By examining these issues, this report addresses water (in)security[2] in the context of climate change.

The report is not intended as a detailed review of the potential impacts of climate change on water but seeks to provide a fact-based, water-focused contribution to the knowledge base on climate change. It is complimentary to both the scientific assessments and the international political frameworks, with the goals of i) helping the water community tackle the challenges of climate change and ii) informing the climate change community about the opportunities that improved water management offers in terms of adaptation and mitigation.

The report illustrates the key challenges in the water domain stemming from climate change, and serves as a guide for concrete actions to address these challenges, supported by examples of responses and their effects from across the world. It addresses the interrelations between water, people, environment and economics in a changing climate. It also illustrates how climate change cannot be an excuse to cover up poor water management, and how climate change can be a positive catalyst for improved water management and water governance.

1.2 A cross-sectoral challenge and the need for integrated assessments

Societies and ecosystems are highly dependent on water. As a result, water management is critical to sustainable development in all its dimensions. The projected reduction in water availability in many regions as a result of climate change puts the achievement of sustainable development under severe pressure. Agriculture and energy are the largest water users globally and are therefore central to finding sustainable solutions. The industrial sector has a substantial and rapidly increasing demand for water.

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[2] *"Water security is the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability."* (UN-Water, 2013).

Supplying drinking water requires available and accessible sources of high-quality water. Adequate treatment of wastewater is very limited or lacking in many countries (WWAP, 2017), rendering high volumes of freshwater unfit for human use and a number of other purposes. Finally, ecosystems, whether freshwater, coastal, marine or terrestrial, require water to sustain the provision of services, which are indispensable for human well-being.

Water-related climate risks cascade through food, energy, urban, transportation and environmental systems with mutual and conflicting influences. Therefore, a cross-sectoral approach is needed to not only address the potential impacts of climate change within a sector, but also the interactions between the sectors. Production of biofuels as a mitigation measure, for instance, requires water and arable land that will consequently not be available for food production, leading to trade-offs between water use, energy security and food security (see Box 9.1). Dams, often built for hydropower as a mitigation measure to reduce GHG emissions by substituting fossil-fuel powered energy production, can also contribute to flow regulation, flood control and availability of water for irrigation. However, reservoirs can 'consume' much water through evapotranspiration and under certain circumstances be net emitters of GHGs. Moreover, poorly designed and/or managed hydropower plants may cause negative ecological impacts on existing river ecosystems and fisheries, and social disruption and human rights violations, among others (Bates et al., 2008; World Bank, 2016a). Therefore, sustainable development requires looking at various sectors and aspects, including agriculture, energy, transportation, industry, cities, human health, ecosystems and the environment, as well as their interrelationships through water.

Integrated assessments that take the nexus between the various sectors into account are necessary to identify the cross-sectoral impacts and to formulate a coordinated response, balancing different sectoral water-dependent objectives and ecosystem needs (Roidt and Avellán, 2019). Policy-makers around the world face common challenges: improving coherence between sectoral policies, balancing economic growth with social, environmental and climate action, and using resources more efficiently and effectively. A common ground for compromise needs to be found to effectively address trade-offs between development and environmental protection, and also between the diverging interests of the various economic sectors. At the same time, applying a nexus approach can bring mutual benefits between, among others, energy, agriculture, ecosystems and water efficiency (FAO, 2014; IRENA, 2015). It can also help establish coherence between sectoral policies and avoid potential conflicts between sectors. As intersectoral impacts can traverse borders, the transboundary aspects should also be taken into account (UNECE, 2018a).

There is a growing awareness that nature-based solutions (NBS), which are inspired and supported by nature and which use or mimic natural processes, can contribute to the improved management of water while providing ecosystem services as well as a wide range of secondary co-benefits, including adaptation, mitigation and resilience to climate change (IPCC, 2014a; UNEP/UNEP-DHI Partnership/IUCN/TNC/WRI, 2014; WWAP/UN-Water, 2018). For example, healthy wetlands can store carbon and simultaneously reduce flood risk, improve water quality, recharge groundwater, support fish and wildlife, and provide recreational and tourism benefits (WWAP/UN-Water, 2018). In urban areas, green infrastructure (or low-impact development) approaches might be used to accommodate projected climate change. These approaches also have a variety of co-benefits, such as climate change mitigation as well as other ecological and social benefits. Hence, NBS can help to respond to the impacts of climate change on water resources and contribute to people's health and quality of life by supporting sustainable food production, improving human settlements, providing access to water supply and sanitation services, and reducing the risks of water-related disasters (UNEP/UNEP-DHI Partnership/IUCN/TNC/WRI, 2014; WWAP/UN-Water, 2018). Application of NBS thus implicitly necessitates integrated approaches.

Adaptation measures are generally designed to deal with climate change impacts without necessarily considering their effects on GHGs, whereas mitigation measures are rarely considered in light of their adaptation potential or their impact on water resources. However, it is possible to incorporate mitigation in designing and selecting adaptation measures in water management. For instance, several NBS for water offer a potential for increased carbon capture and storage. Wetland restoration as an adaptation option can result in improved water quality and decreased flooding, and also contribute to mitigation through CO_2 absorption and carbon capture. In many cases, it can also lead to cost savings when compared to built infrastructure solutions. However, net carbon storage, including possible CH_4 and NO_x emissions, needs to be considered as well. Afforestation and reforestation may also have beneficial hydrological and mitigating effects (Bates et al., 2008; Tubiello and Van der Velde, 2011; Wallis et al., 2014), but since adverse effects due to the water requirements of the vegetation have also been demonstrated (Schwärzel et al., 2018), careful planning is required in order to achieve a beneficial effect in terms of soil water infiltration and deep percolation under different circumstances (SIWI, 2018). Water efficiency measures can help mitigation by reducing energy needs for processing, transporting, and treating water and wastewater, and for better processing and disposing of sludge and other forms of waste. Conversely, mitigation measures can have negative impacts on water. For instance, the electrification of personal/private vehicles will likely still have significant GHG and water footprints if the source of the electricity is not renewable. This underlines the need for comprehensive and coordinated policy-making and planning.

1.3 The most vulnerable

The developed world is responsible for much of the anthropogenic GHG emissions driving climate change. The concentrations of GHGs started accumulating in the atmosphere at beginning of the nineteenth century, coinciding with a period of rapid industrialization, and have been increasing ever since (Mgbemene et al., 2016; Dong et al., 2019; IPCC, 2018a). However, much of the impacts of climate change will be manifested in the tropical zones where most of the developing world can be found. Another discrepancy is that developing countries have a lower ability to respond to climate change impacts, and the poorest groups and societies are the most vulnerable to minor and major shocks. Many of the developing countries are short of the financial resources for adaptation and mitigation efforts, and for some, the capacity to act may also be hindered by poor governance (Das Gupta, 2013). Also, many developing countries lack a knowledge base on water-related disaster management, and on water availability, demand and use.

Much of the impacts of climate change will be manifested in the tropical zones where most of the developing world can be found

Scientific evidence has revealed numerous discernible impacts of climate change on natural, managed and human systems worldwide (IPCC, 2014a). There is high confidence that warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system (IPCC, 2018a). While many developing countries emphasize the historical responsibility of the developed world when it comes to GHG emissions, many developed countries have remained reluctant to bear the full burden of climate responsibilities. From this, the concept of climate justice has emerged, stressing that climate change is an ethical and political issue as well as an environmental and physical one. In this light, the Paris Agreement also refers to equity, climate justice and human rights.

The effects of multiple other drivers acting on natural and especially human and managed systems (e.g., land use change, population growth, technical developments) have either been collectively greater than the effects of GHG emissions or made it difficult to determine the relative importance of these emissions as a driver (Stone et al., 2013). In some situations, inherently poor water management practices are important contributing factors to water-related problems. Funds, like the Adaptation Fund established under the Kyoto Protocol of the United Nations Framework Convention on Climate Change, have been made available for developing countries to improve their water management and to better adapt to climate change. One of the issues in making these funds available is demonstrating the extent to which existing problems can be attributed to climate change. The potential cumulative effects of multiple non-GHG emissions drivers ('confounders') can create attribution challenges that, as a result, leave developing countries with challenges in fulfilling the 'burden of proof' required to receive funding in support of appropriate adaptation and risk management approaches (Huggel et al., 2016).

The impacts of climate change on the availability of water resources over space and time affect the poor disproportionately through their effects on agriculture, fisheries, health and natural disasters. Nearly 78% of the world's poor, approximately 800 million people, are chronically hungry while two billion suffer micronutrient deficiencies (FAO, 2017a). They largely live in rural areas and rely mainly on rainfed agriculture, livestock or aquaculture to sustain themselves and their families – all of which are highly climate- and water-dependent and therefore at risk to hydro-meteorological irregularities. With increased rainfall variability in many regions, they will become increasingly vulnerable and their opportunities for rising out of poverty will likely diminish. Moreover, agricultural production shocks may trigger significant increases in the price of food and lead to food insecurity, for inhabitants of both rural and urban areas. As poorer households spend a significantly larger share of their income on food, they will be the most impacted (World Bank, 2016a).

These impacts are particularly felt by poor women and girls, who often experience inequalities in the access to water, sanitation and hygiene (WASH) services and to the water resources that they often depend upon for their livelihoods. Likewise, indigenous peoples are notably sensitive to the effects of climate change, especially when they are unable to apply traditional knowledge and strategies for adaptation to environmental changes and mitigation of its effects. Children are disproportionately affected but, along side youth, can also influence and participate directly in efforts to learn about, prevent, prepare for, cope with and adapt to climate change and extreme events (Haynes and Tanner, 2015). The Paris Agreement in this respect refers to intergenerational equity (UNFCCC, 2015).

The frequency and intensity of floods, droughts and storm surges are expected to increase with climate change. Poor households tend to be more exposed to the impacts of droughts and urban floods than their wealthier counterparts (see Chapter 8). This is primarily because the rural poor disproportionately rely on agricultural income, which is most at risk from droughts. Poorer families in urban areas are more likely to live in flood-prone areas because land is scarce and higher risk zones are valued lower, making them more affordable (Winsemius et al., 2015; World Bank, 2016a).

Climate change and the related water challenges are not only complex and interconnected, they are also intergenerational

Increased water scarcity and variability in availability may also lead to greater exposure to contaminated waters, insufficient water available for sanitation and hygiene, and subsequent increased disease burdens (see Chapter 5). These impacts will disproportionately affect poor households who may already lack adequate sanitation and reliable safe water supplies. Climate change will increase incidences of diarrhoea and other waterborne diseases, causing healthcare costs and days lost at work or school. Such losses are often cited as the reason why households fall into poverty (World Bank, 2016a).

In addition to being more exposed to extreme events, poor households tend to lose a higher share of their assets due to storms or floods because their low-quality houses tend to suffer relatively more damage. Poor people tend to have most if not all of their assets in material form, making them all the more vulnerable to extreme events. They also have limited access to recovery support, such as insurance, social protection and credit (Winsemius et al., 2015; World Bank, 2016a).

Although climate change affects all groups in society, the magnitude of impacts on women and girls are much greater, increasing gender inequalities and threatening their health, well-being, livelihoods and education. In times of drought, women and girls are likely to spend longer periods of time collecting water from more distant sources, putting girls' education at risk because of reduced school attendance. Women and girls are exposed disproportionately to risks of waterborne diseases during floods due to a lack of access to safe water, the disruption of water services and increased contamination of water resources. Climate change will also jeopardize the livelihoods of women farmers in developing countries who depend heavily on access to water resources for food and crop production. Women make up on average 43% of the agricultural labour force in developing countries (Oxfam International, n.d.), as compared to about 35% in Europe (Eurostat, 2017) and 25% in the United States of America (USA) (USDA, 2019). The proportion can be much higher, such as in Kenya, where about 86% of farmers in 2002 were women (FAO, 2002). The out-migration of males can lead to an increased role of women in agriculture in terms of greater workloads (Miletto et al., 2017; FAO, 2018a). For these and other reasons, a gendered approach to the differential impacts of climate change on women and men, combined with the participation of women in climate-related policy development, is required. The need for disaggregated data on climate change, including by gender, is critical for the development of appropriate gender-sensitive and transformative policies (Miletto et al., 2019).

Diminishing water supplies can translate into lower economic prospects, particularly in terms of agricultural and industrial production. Climate change disproportionately affects food-insecure regions, jeopardizing crop and livestock production, fish stocks, and fisheries, primarily because protection levels and overall water quality are lower in poor countries (Winsemius et al., 2015; FAO, 2017a). Some regions could see sustained negative economic growth as a result of water-related losses in agriculture, health, income, and property. Poorly designed water management policies can exacerbate the negative impacts of climate change, while on the other hand well-designed policies can go a long way towards neutralizing them. Such policies therefore need to be based on an extensive and sound knowledge and scientific basis. Some regions stand to see economic growth accelerate with improved water resource management. *"When governments respond to water shortages by boosting efficiency and allocating water to more highly-valued uses, losses [in terms of GDP] can decline dramatically and may even vanish"* (World Bank, 2016a, p.14). However, it is essential that the allocation of water to such higher-value uses also takes account of any potentially negative impacts on water resources, the human rights to water and sanitation, and the environment.

When economic prosperity is impacted by rainfall, episodes of droughts and floods, this can lead to waves of migration and spikes in violence within countries – 18.8 million new internal displacements associated with disasters were recorded in 135 countries and territories in 2017 (IDMC, 2018). Moreover, water scarcity is likely to limit the creation of decent jobs, since about three out of four jobs constituting the global workforce are dependent on water (WWAP, 2016). Conflicts further reduce food availability, pushing many affected people back into poverty and hunger (FAO, 2017a). In a globalized and connected world, such problems are impossible to quarantine and attribute to a specific cause. A range of economic, social and political drivers, especially where large inequities prevail, make people move from zones of poverty to regions of prosperity, which can lead to increased social tensions (Foresight, 2011). Economic prosperity and poverty alleviation are thus closely tied, with the latter highly dependent on the former. Across all nations, a 1% increase in mean income has been associated with a 2 to 3% reduction in the number of people within a country living below the poverty line (World Bank, 2016a). In this way, water management is closely linked to the socio-economic status of countries as well as to the vulnerability of individuals.

Some areas are more vulnerable to climate change as a result of their geographical conditions. These include Small Island Developing States (SIDS) that are vulnerable to possible changes in rainfall patterns. When rainwater is the primary source of water, a reduction in rainfall may decrease the volume of available freshwater. This vulnerability can be further aggravated by sea level rise, which may reduce or contaminate surface and subsurface water resources because of saline intrusion. Coastal areas in general, including SIDS, are under the influence of a combination of sea level rise and more extreme storms as a result of climate change. Mountainous areas may undergo a change from mainly snow-covered to mainly snow-free as a result of increasing temperatures. This may trigger the release of loose rock and soil in former permafrost areas and exacerbate the danger of rockfall, debris flows and mud flows, especially when combined with more intense rainfall. A specific risk is the build-up of glacial lakes and the threat of lake outbursts. All this could result in human casualties and the destruction of property. Drylands are already vulnerable as a result of limited rainfall and many of them are expected to receive less rainfall or have more variable rainfall as a result of climate change, which will put additional stress on agricultural production and will enhance the risks of desertification.

Climate change and the related water challenges are not only complex and interconnected, they are also intergenerational. Decisions being made today will be felt by future generations. Accounting for next generations is therefore imperative. Increasing numbers of academic programmes and specializations in water- and climate-related issues in the past decades have given rise to a generation increasingly equipped to deal with climate change issues.

The preceding outlines the compelling and complex interactions between humankind and the environment, in particular with respect to water and climate change. It also highlights the need for appropriate adaptation and mitigation approaches that will allow human populations to live in balance with the resulting changing environment, while growing and developing in a sustainable and equitable manner. Good water governance and improved water resources management are fundamental and essential requirements to success. The following chapters look into these issues in more detail and discuss ways to address global, regional and local challenges.

2

International policy frameworks

Opening of the 71st session of the United Nations General Assembly in New York.

SIWI | Maggie White[3]

WWAP

With contributions from: John Matthews and Ingrid Timboe (AGWA); Yoshiyuki Imamura (ICHARM); Marianne Kjellén (UNDP); Rio Hada (OHCHR); and Francesca Bernardini, Sonja Koeppel and Hanna Plotnykova (UNECE)

This chapter reviews the major international policy frameworks, highlighting existing gaps and opportunities for linkages in terms of resilient water management that could inhibit or enhance progress on global climate action and sustainable development.

2.1 Introduction

Over the past four decades, the international community, principally through United Nations policy-making processes, has been concerned with unsafe water and sanitation, and the challenges arising from growing demands on the world's water resources to meet human, economic and environmental needs. At the same time, climate change has emerged as an existential threat to human well-being and the effective enjoyment of all human rights, further imperiling water security for hundreds of millions of people, as well as ecosystems worldwide. As such, international policy frameworks addressing climate change must take water into account, even more because water is key to reducing carbon emissions and adapting to an increasingly variable climate. Unfortunately, fundamental detachments between water management and international policy remain prevalent.

The 2002 World Summit on Sustainable Development, with its Millennium Development Goals, laid out the foundations for the 2030 Agenda for Sustainable Development adopted in 2015, alongside two other major global agreements, the Paris Agreement on climate change and the Sendai Framework for Disaster Risk Reduction. These international policy frameworks formed a historic step forward in addressing the most pressing global challenges, yet they still suffer from some of the problems of earlier agreements. While in spirit, the 2030 Agenda acknowledges the importance of interlinking the Sustainable Development Goals (SDGs), this integration has not translated into practice, and issues of poverty reduction, health and sanitation, environmental degradation, climate change, and disaster risk are still addressed in separate 'silos' at the global and national levels. Furthermore, integration between the global agendas has also been lagging.

2.2 Overview of the main agreements

2.2.1 2030 Agenda for Sustainable Development

The 2030 Agenda for Sustainable Development describes a trajectory for global development where the entire suite of goals constitutes a pathway to 'transforming our world' in order to reach the future we want whilst leaving no one behind. It mentions rising inequalities, natural resource depletion, environmental degradation and climate change as being the greatest challenges of our time. It recognizes that social development and economic prosperity depend on the sustainable management of freshwater resources and ecosystems, and highlights the importance of the integrated nature of SDGs (UNGA, 2015).

Within the 2030 Agenda, water serves as an (often) unacknowledged but essential connecting factor for reaching the SDGs (Figure 2.1). Water is essential for basic human needs, as described in the SDGs on the human rights to water and sanitation for all (SDGs 6, 5), but also for marine (SDG 14) and land (SDG 15) ecosystems, for producing food (SDG 2) and energy (SDG 7), supporting livelihoods (SDG 8) and industry (SDGs 9, 12), and providing sustainable and healthy environments to live in (SDGs 1, 3, 11) (Sweden, 2018).

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[3] Commissioned by UNDP-SIWI Water Governance Facility.

Figure 2.1 Connecting the dots

Source: Developed by the Stockholm Environment Institute for Sweden (2018).

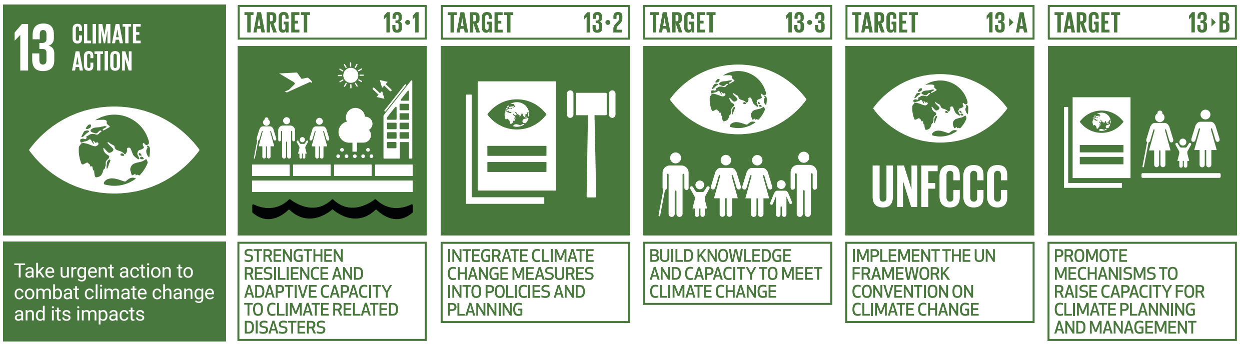
Water has a critical role to play in both mitigation of and adaptation to climate change (SDG 13) and, in that capacity, contributes to building resilient, just, peaceful and inclusive societies (SDG 16) (White, 2018).

While SDG 13 'Take urgent action to combat climate change and its impacts' includes specific targets and indicators, it also explicitly acknowledges that the United Nations Framework Convention on Climate Change (UNFCCC) is the primary international forum for negotiating and overseeing the global response to climate change (see next section). Without necessarily specifying water-related issues, several of the targets and indicators in SDG 13 (Figure 2.2) are relevant for water or dependent on water (13.1, 13.2, 13.B). But SDG 13 is also emblematic of the fundamental disconnection between the SDGs themselves, and between the 2030 Agenda and other global frameworks. For example, there is no formal mechanism linking SDG 13 to the goals of the Paris Agreement, resulting in parallel processes.

Given water's role in mitigating and adapting to climate change, water could play a connecting role both across the SDGs and across policy frameworks such as the Paris Agreement.

An integrated approach to the 2030 Agenda recognizes that most aspects of society, development, sustainable growth and the environment are symbiotic. Yet during the 2018 July session of the High-Level Political Forum (HLPF), when SDG 6 was reviewed, amongst other SDGs, and Voluntary National Reports were presented, countries acknowledged that the SDGs were being addressed in a siloed manner and that they were not on track to meet the targets of SDG 6, particularly for the poorest and most vulnerable communities (HLPF, 2018).

Figure 2.2 SDG 13: Water-relevant and water-dependent targets



Sources: United Nations Sustainable Development Goals Knowledge Platform and Project Everyone.

Furthermore, SDG 6, like the other SDGs, has targets that are universally applicable and progressive. However, each government must decide how to incorporate them into national planning processes, policies and strategies based on national realities, capacities, levels of development and priorities (United Nations, 2018a). In the climate arena, this is addressed by specific national-level mechanisms that were agreed upon at the 21st Conference of the Parties (United Nations Climate Change Conference 2015, COP21) within the Paris Agreement (see section below and Chapter 11). Hence, there is a unique opportunity to interlink the implementation of the global agendas at the national and local level by mainstreaming and addressing water-related issues in an integrated and systemic manner when addressing the climate commitments.

2.2.2 Paris Agreement on climate change

The UNFCCC entered into force in 1994, after being formally adopted during the Rio Earth Summit in 1992. Within the UNFCCC, legal instruments, or ‘protocols’, have been employed to reach the goals of the Convention. The Paris Agreement adopted at COP21 was quickly ratified and went into effect on the eve of COP22, which took place in 2016 in Marrakech, Morocco.

The Paris Agreement's long-term goal is “*holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change*” (UNFCCC, 2015, Article 2). The Agreement focuses on dealing with climate change mitigation and adaptation, as well as the financial needs required to reach this goal. Unfortunately, the outcomes of COP25 in 2019 appear to suggest that meeting Paris Agreement's long-term goal may be even more difficult than earlier anticipated.

How it functions

Under the Paris Agreement, each Party has committed to determine, plan and regularly report on the measures it will undertake to mitigate and adapt to climate change. These measures, known as nationally determined contributions (NDCs), are to be reviewed every 5 years. The next round of NDCs (new or updated) are to be submitted in 2020. NDCs are designed to be progressive and NDC reporting on adaptation measures is entirely voluntary.

Separately from the NDCs, Parties to the UNFCCC are also encouraged to develop National Adaptation Plans (NAPs). These plans are meant to identify medium- to long-term adaptation needs and develop the strategies needed to address them. Ideally, NAPs take into consideration the 2030 Agenda and work to integrate the SDGs and their targets where appropriate. As such, with a high level of alignment of SDG targets and ambitions in the NDCs, delivering on NDCs and NAPs should help countries achieve their SDGs and achieving the SDGs should facilitate countries’ efforts to mitigate and adapt to climate change (Hamill and Price-Kelly, 2017; Northrop et al., 2016).

In addition, the Paris Agreement specifically acknowledges the need to address loss and damage, since many climate change effects cannot be avoided by adaptation measures alone. It specifies that loss and damage can take various forms – both as immediate impacts from extreme weather events or as slow-onset impacts, such as the loss of coastlines due to sea level rise (section 2.2.3). Here water management interventions can act as a bridge and offer remedies, including so-called nature-based solutions (NBS), that can help communities and ecosystems prevent, adapt and recover from disasters.

The Paris Agreement also recognizes the essential roles that non-state parties, such as local authorities, the private sector, academia, civil society organizations, international and non-governmental organizations, foundations, women, indigenous peoples, and youth groups play in reaching its goals (UNFCCC, 2015). The Global Climate Action Agenda (known as the Marrakech Partnership Global Climate Action Agenda – MPGCA) (UNFCCC, 2019) enables non-state parties to contribute to the UNFCCC, highlight solutions and demonstrate concrete actions on the ground. Upon the initiative of the water community, water has an official ‘voice’ within the MPGCA,[4] meaning that there are UNFCCC-sanctioned water and climate events at each COP, and water is one of the permanent thematic groups represented in the MPGCA.

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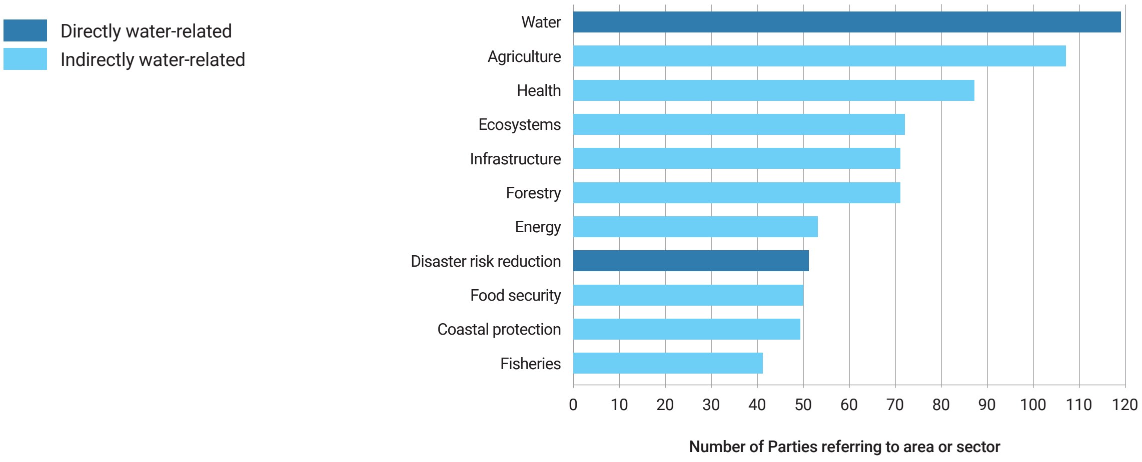
[4] Participating organizations included AGWA, ARUP, CDP, CEO Water Mandate, Deltares, FAO, FWP, INBO, SIWI, SUEZ, UNESCO, WRI and WWC non-exhaustive list. In July 2016, SIWI coordinated and submitted, on behalf of several international organizations an official letter to COP21 and COP22 champions promoting the added value of having a specific focus on water in the MPGCA.

Since the ratification of the Paris Agreement, tangible steps have been taken to reduce greenhouse gas emissions and initiate adaptation measures, with over 160 countries and the European Union submitting Intended NDCs (INDCs) (Northop et al., 2016). However, as the latest Special Report of the Intergovernmental Panel on Climate Change (IPCC) indicates, there is still a long way to go in order to reach the objectives of the agreement (IPCC, 2018b). The need to raise ambitions was highlighted in the closing plenary session of COP24 by Frank Bainimarama, Prime Minister of Fiji and President of COP23, who noted that the world needed "*five times more ambition, five times more action*" in order to achieve the goals of the Agreement (UN News, 2018).

Water in the Paris Agreement – a hidden treasure

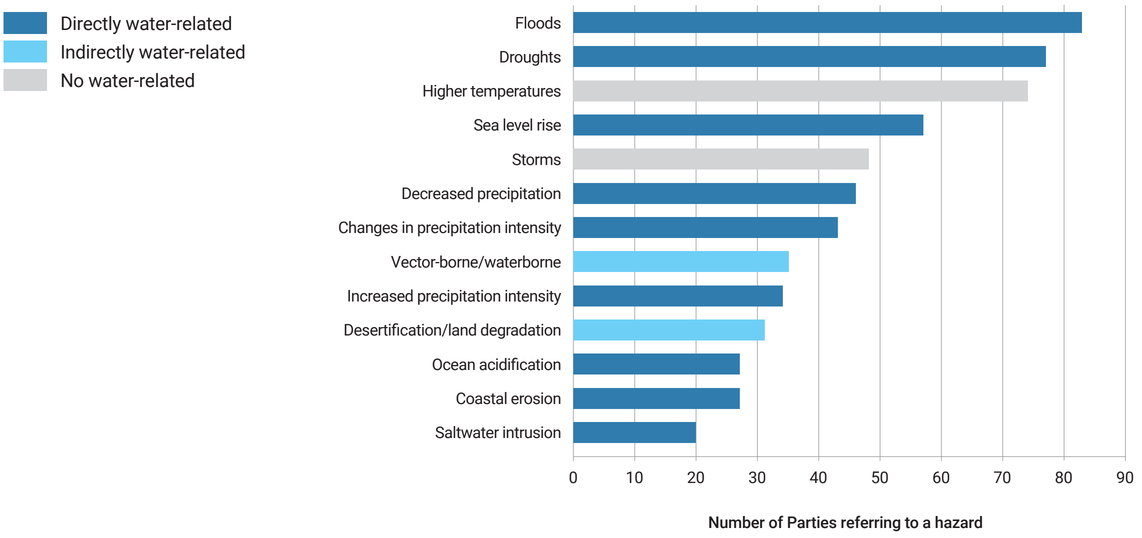
Although water is not mentioned in the Paris Agreement *per se*, it is an essential component of nearly all the mitigation and adaptation strategies – from carbon storage in terrestrial ecosystems, to emerging clean energy technologies, to adapting to extreme weather events (White, 2018). Water is identified as the number one priority for most of the INDC's adaptation actions and is directly or indirectly related to all other priority areas (Figure 2.3). Most identified hazards are also water-related (Figure 2.4).

Figure 2.3 Priority areas and sectors for adaptation actions identified in the adaptation component of the communicated INDCs



Source: Adapted from UNFCCC (2016, fig. 16, p. 69), including GWP's analysis.

Figure 2.4 Key climate hazards identified in the adaptation component of the communicated INDCs



Source: Adapted from UNFCCC (2016, fig. 14, p. 64), including GWP's analysis.

Furthermore, since many of the SDGs and their relevant targets are addressed by these INDC priorities, transforming water-related commitments into national adaptation/action plans gives countries and cities the opportunity to address the needs in an integrated, holistic, effective, efficient and sustainable manner in order to build resilient societies.

Outside the UNFCCC, independent groups such as the NDC Partnership are working to connect the SDGs with the NDCs and NAPs. The partnership is an opportunity for international water organizations to become members and support the delivery in 2020 of more ambitious, reviewed NDCs that further integrate water into the operational phase of the NDCs and NAPs.

2.2.3 Sendai Framework for Disaster Risk Reduction 2015–2030

On 18 March 2015, UN Member States adopted the Sendai Framework for Disaster Risk Reduction 2015–2030 ("Sendai Framework"). This non-binding framework is comprised of seven standard global targets and four priorities for action designed to achieve *"the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries"* (UNDRR, 2015a).

In pursuit of this outcome, Member States must develop publicly available national and local disaster risk reduction (DRR) strategies by 2020 (Target E). Non-Member stakeholders are also invited to showcase voluntary commitments to help the United Nations Office for Disaster Risk Reduction (UNDRR) monitor and disseminate action to achieve the Sendai Framework targets.

Prior to the Sendai Framework, global DRR strategies focused primarily on disaster relief activities. One of the primary purposes of Sendai Framework is to promote active prevention and improved rebuilding strategies aimed at increasing resilience and reducing long-term risk from both sudden and slow-onset hazards within and across sectors at the local, national and international levels (Priorities 3 and 4). This shift from disaster relief to prevention and preparedness remains an ongoing process mediated by complex interactions between a number of disaster drivers including climate change, inequality, demographic change and population distribution, as well as environmental degradation (Briceño, 2015).

While water is seldom mentioned in the Sendai Framework itself, water flows through each of the priorities for action and is central to all seven targets. Floods and storms account for nearly 90% of the most severe natural disasters (Adikari and Yoshitani, 2009). Water-related hazards are particularly sensitive to even small shifts in climate, so that the frequency, magnitude and intensity of these hazards are shifting over time (Milly et al., 2005).

Recognition of the clear linkages between water, climate change and disaster predate the Sendai Framework. Since 2007, the UN High-level Experts and Leaders Panel on Water and Disasters (HELP) has been working to raise awareness about the connections between water and disasters (Box 2.1) and strives to bridge the gaps between their respective policy communities.

2.2.4 International water conventions

Global legal and intergovernmental frameworks on water, such as the United Nations Convention on the Law of Non-Navigational Watercourses (Watercourses Convention) and the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention), provide a framework for addressing the impacts of climate change on water resources.

Many provisions of international water law support climate change adaptation measures, such as the principles of equitable and reasonable use, 'no significant harm', and the precautionary principle (UNECE/INBO, 2015). Therefore, although the Water Convention does not explicitly mention climate, it provides a powerful tool for cooperation by requiring Parties to prevent, control and reduce transboundary impacts on water resources, including those related to adapting and mitigating climate change.

At the regional level, the Protocol on Water and Health helps to protect human health and well-being by improving water management and reducing water-related diseases impacted by climate change.

While the transboundary water frameworks guidelines have been ratified or signed by several countries, non-compliance and obstacles to the expansion of transboundary cooperation remain. Nevertheless, the urgent need for cooperation in addressing climate change can act as an incentive for wider cooperation in transboundary basins.

2.3 Water as a connector to support the implementation of global agreements

When it comes to water and climate change within the 2030 Agenda, both SDG 6 and SDG 13 have a direct or indirect impact on all the other SDGs. The challenges of development, poverty eradication and sustainability are intricately interwoven with those of climate change mitigation and adaptation, especially through water. Water is not a sector, but a connector and the impacts induced by climate change touch all aspects of our society (economic, social and environmental) (White, 2018). Strong political will and leadership are needed to highlight and mainstream water's value in implementing the global agreements (Figure 2.5).

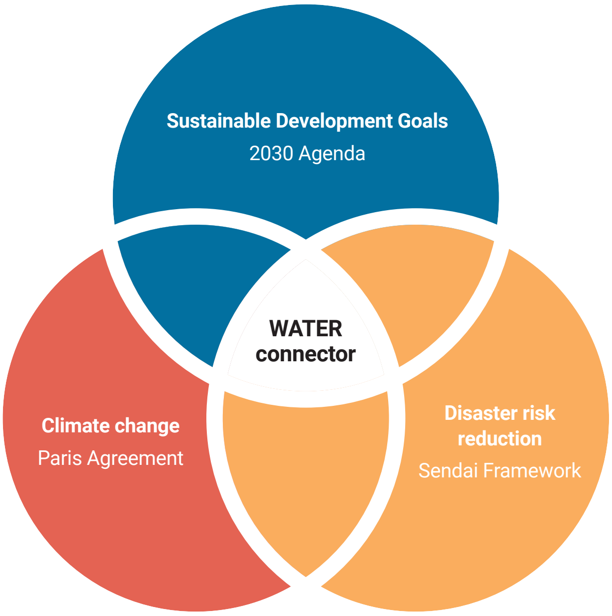
Several initiatives led by Heads of State, Member States and the United Nations have been launched in order to bridge divides and find means to implement the goals of the global agreements in a more efficient and sustainable manner (Box 2.1). These initiatives recognize water as a connector and facilitator in implementing the global agendas. Yet there is a discrepancy when it comes to transforming these global recommendations and policies into concrete actions on the ground.

While these efforts may be laudable, further blending of insights, perspectives and financial mechanisms from the water, DRR and climate change communities would be mutually beneficial, increase cost-effectiveness, and help ensure that their respective choices do not undermine or inadvertently heighten risks for others (Matthews et al., 2018).

Where water is often considered a stand-alone sector, it is essential that water is recognized as a connector. For instance, although water is relatively high on the adaptation agenda, NDCs do not offer options for improving water management decision-making, policies and intersectoral institutions at the national level in order to reach the targets and avoid difficult trade-offs and conflicts. Some progress in this direction was made at the 74th United Nations General Assembly (UNGA) held in September 2019 (Box 2.2).

Water goes beyond water, sanitation and hygiene (WASH) and water resource management. Water is the basis for all life on Earth and a basic human right. Streamlining water into global climate, development and DRR processes could be a means of connecting climate change issues with all the other SDGs. Placing water at the heart of these strategies is an essential way forward and would help the water community deliver its message to the climate community and a broader audience.

Figure 2.5 Water as a connector among the global commitments adopted in 2015



Source: UN-Water (2019, p.9). © 2019 United Nations. Reprinted with the permission of the United Nations.

Box 2.1 High-level initiatives launched by Heads of State and the United Nations

In 2016, UN Secretary-General Ban Ki-moon and World Bank Group President Jim Yong Kim launched a High-Level Panel on Water, consisting of a number of Heads of State, government representatives and a special advisor chartered for a two-year period. In March 2018, the High-Level Panel released its report *Making Every Drop Count: An Agenda for Water Action* (HLPW, 2018a), highlighting the enabling aspects of water for implementing a wide variety of the Sustainable Development Goals (SDGs). The recommendations from this report may be a useful vehicle to articulate the interdependence of the SDGs, the Paris Agreement and the Sendai Framework for long-term sustainability, particularly concerning resilience and reducing the impacts of water-related disasters.

The High-Level Experts and Leaders Panel on Water and Disaster (HELP/UNSGAB) was established upon request of the UN Secretary-General's Advisory Board on Water and Sanitation (UNSGAB) in 2007 to raise global awareness and promote tangible actions in addressing issues of water and disasters, by releasing reports and biannually co-convening UN Special Thematic Sessions on Water and Disasters. The aim of HELP is to urge countries to take preventive actions against increased frequencies and even higher impacts of water-related disasters due to climate change, population growth and rapid urbanization. It calls for disaster risk reduction, water resources management and climate adaptation to no longer be treated as separate topics.

The International Decade for Action on Water for Sustainable Development, 2018–2028, was launched in March 2018, after being adopted by the 71st United Nations General Assembly (UNGA), with the aim to accelerate efforts to meet water-related challenges, including limited access to safe water and sanitation, increasing pressure on water resources and ecosystems, and the exacerbated risk of droughts and floods. One of the key objectives of the Decade is for the international community to energize implementation of existing programmes and projects, such as the 2030 Agenda for Sustainable Development, the 2015–2030 Sendai Framework for Disaster Risk Reduction and the 2015 Paris Agreement, in a coordinated and effective manner to further improve cooperation, partnership and capacity development. The mid-term review of the Decade in 2023 will highlight how water has been addressed as an enabling factor for implementing the global agendas (United Nations, 2018b).

Box 2.2 Progress at the 74th United Nations General Assembly (September 2019)

Several summits on climate action, sustainable development and financing for development were held on the margins of the 74th session of the United Nations General Assembly (UNGA) in September 2019. Heads of State and country delegations assembled in New York to reaffirm their commitment to deliver on these agendas. In calling for the summits, António Guterres, the Secretary-General of the United Nations, specifically asked states *"not to come to the Summit with beautiful speeches … the ticket to entry is bold action and much greater ambition"* (UN Secretary-General, 2019), highlighting the emergency of the situation.

The political declaration of the High-Level Political Forum (HLPF), unanimously adopted by the UNGA, validated the next five-year cycle of the 2030 Agenda and highlighted the countries' dedication to 'leaving no one behind'; reducing disaster risk and building the resilience of countries, economies, communities and individuals to economic, social and environmental shocks and disasters; as well as improving data collection and reporting at global and national level (HLPF, 2019). Furthermore, world leaders took note of the Secretary-General's progress report on the Sustainable Development Goals (United Nations, 2019) and the *Global Sustainable Development Report* (Independent Group of Scientists appointed by the Secretary-General, 2019) and acknowledged the importance of a systemic and holistic approach, taking into account interlinkages between goals and targets.

Last but not least, within the UN Climate Action Summit, the Global Commission on Adaptation (GCA) presented its flagship report *Adapt Now: A Global Call for Leadership on Climate Resilience* and called for 2020 to be the Action Year for Adaptation. Water has a prominent place in the GCA's report, and a dedicated Water Action Track was announced in order to foster adaptation through resilient water management (GCA, 2019).

Among the main outcomes of these summits is that world leaders, pressed by citizen and youth movements, called for a decade of ambitious action to 'leave no one behind' and announced specific actions to advance the implementation of their engagements. There is a renewed commitment to ensure the lasting protection of the planet and its natural resources, including freshwater, and to protect and conserve our planet's marine and terrestrial resources, recognizing their key role in adapting to and mitigating the impacts of climate change. Many countries and Heads of State also highlighted the importance of delivering on the water resource management and sanitation goals.

The main challenge will be to pool all these intentions and initiatives into a comprehensive and coherent process that enables concerted and amplified action plans instead of isolated and parallel processes at the global, regional, national and local level. Identifying the water initiatives announced at these summits and highlighting how they complement and feed into one another would be an efficient way of moving forward and ensuring that funding opportunities and bottlenecks identified at the Financing Development Summit (2019) are addressed.

3

Water availability, infrastructure and ecosystems

Aerial view of a sewage treatment facility.

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This chapter establishes linkages between climate change and various aspects of water management. Adaptation and resilience-building options are presented with respect to water storage – including groundwater – and water supply and sanitation infrastructure, and unconventional water supply options are described. Mitigation options for water management systems are also presented.

3.1 Impacts on water resources and infrastructure

3.1.1. Water scarcity, ecosystem degradation and water pollution

As noted in the Prologue, climate change exacerbates water scarcity. Depending on how water scarcity is defined and interpreted (Falkenmark et al., 1989; Seckler et al., 1999), climate change brings contrasting challenges to different regions. Economic water scarcity is normally caused by a lack of water infrastructure that can ensure access to water (Comprehensive Assessment of Water Management in Agriculture, 2007), and occurs typically in Africa and some parts of South America and South Asia. Developing more water infrastructure in these regions is the only way to alleviate scarcity, but it should take into account the impacts of climate change that are already observed (or are likely to occur). Physical water scarcity, on the other hand, due to excessive withdrawals and well-developed infrastructure for human use or due to natural aridity, typically occurs in Australia, Central Asia, Middle East and North Africa, Northern China, and Southern Africa.

Water sustains both terrestrial (forests, grasslands, etc.) and freshwater ecosystems (rivers, lakes and wetlands), which provide important services such as water supplies, natural purification, food production, cultural values and economic activities. Yet, on top of the impacts of climate change, rapidly occurring ecosystem degradation due to pollutants from industrial, mining and agricultural activities, untreated urban and rural waste, oil spills, and toxic dumping has caused strong negative effects on biodiversity and freshwater ecosystems, also threatening essential ecosystem services. Around one million animal and plant species are threatened with extinction, and freshwater species are the ones that have suffered the greatest decline, falling by 84% since 1970. More than 85% of global wetlands present in 1700 had been lost by 2000 and continue to disappear at a rate three times faster than forest loss. Since 1970, there has been a 70% increase in numbers of invasive alien species in wetlands (e.g. Asian carp, water hyacinth, nutria) (IPBES, 2019). Water depletion and pollution are the major causes of biodiversity loss and ecosystem degradation, which, in turn, reduce ecosystem resilience, making societies more vulnerable to climate and non-climate risks.

Poor water quality due to eutrophication (mostly from poor sanitation and poor nutrient management) is one of the most widespread problems affecting available water supplies, fisheries and recreational activities. For example, the estimated cost of damage caused by eutrophication in the United States of America (USA) alone is approximately US$2.2 billion annually (Dodds et al., 2009). Climate change is expected to exacerbate water quality degradation as a result of higher water temperatures, reduced dissolved oxygen and thus a reduced self-purifying capacity of freshwater bodies. As floods and droughts are likely to increase due to climate change, there are further risks of water pollution and pathogenic contamination caused by flooding or by the higher pollutant concentrations during drought.

Urbanization is an important pollution source, particularly in developing countries and especially for groundwater, as a result of under-managed solid waste disposal and poorly managed sanitation infrastructure. Even in well-managed sanitation systems, climate change may indirectly exacerbate groundwater contamination risk through the switch to unprotected on-site sanitation and open defecation when droughts limit water availability for flush toilets and proper hygiene practices associated with well-managed sanitation systems (McGill et al., 2019).

Climate change elevates risks to water infrastructure

3.1.2 Threats to water infrastructure

Climate change elevates risks to water infrastructure. More intense and more frequent floods increase the risks of damage to water treatment and supply infrastructure, which can lead to service disruptions. Water and wastewater infrastructure in coastal low-lying cities are more prone to severe flooding (Cain, 2017). Wastewater treatment plants have to deal with increasing incidents of pollution surges caused by floods. Increasing variability in rainfall intensity and patterns caused by climate change have a significant impact on the performance of urban drainage systems, with an increase in combined wastewater and stormwater overflows during heavy precipitation and flooding (Tavakol-Davani et al., 2016).

Another globally emerging issue is ageing water infrastructure (Ansar et al., 2014; Grant and Lewis, 2015; Zarfl et al., 2015), although the pattern of ageing differs between regions. In water storage infrastructure, the issue manifests itself through sedimentation, increased operation and maintenance costs, structural changes, increasing risks of breakage, and overall operational efficiency decline as a structure approaches its design life. But ageing is also influenced by the changing river inflow variability associated with climate change. Increased uncertainty in stationarity of hydrology due to climate change makes it necessary to reassess the safety and sustainability of water storage dams, and to evaluate them for potential modifications or decommissioning, for the minimization of their environmental and social impacts, and for the optimization of their services. Pittock and Hartmann (2011) identified several implications of climate change for the management of existing water storage dams, including the failure of dams due to frequent, extreme and sudden inflows; failure of dams to perform their intended services as a result of climate change; and operational changes of dams imposed by climate change, such as additional storages and inflow/outflow controls.

Somewhat related to the issue of ageing infrastructure is the emerging trend of decommissioning dams that have become either unsafe, obsolete, or socially and environmentally unacceptable. The scale and pace of dam decommissioning is increasing, particularly in areas with a long history of impoundments construction like Europe and the USA (Dam Removal Europe, n.d.; Thomas-Blate, 2018). In the USA alone, over 80 dams were removed in 2017, and in total some 1275 dams were removed in 21 states over the last 30 years. Decommissioning, however, primarily focuses on smaller structures. There are many ageing dams globally with no or limited value today. Removal is often the best option, but it is generally a long-term and costly process.

Conveyance to urban areas and in irrigation is often a bigger bottleneck than storage (PPIC Water Policy Center, 2018), as it has to deal with less predictable peak flows of progressively increasing magnitude and frequency. Many regions will need substantial climate-resilient infrastructure investment to improve water conveyance reliability under climate change.

Water-related extremes exacerbated by climate change increase risks to drinking water, sanitation and hygiene (WASH) infrastructure, such as damaged sanitation systems or flooding of sewer pumping stations. The consequent spread of faeces and associated protozoa and viruses can cause severe health hazards and cross-contamination. Water quality decline exacerbated by climate change increases water purification costs. Furthermore, climate change may compromise the effectiveness of available water storage options – both surface, for examples due to increased evaporation triggered by increased temperature, and sub-surface, for example due to saltwater intrusion in coastal aquifers triggered by climate change-induced sea level rise. Higher sea levels due to climate change also cause saline water intrusion into sewers in coastal areas (Laugier et al., 2010; Rasmussen et al., 2013). Adaptation of water infrastructure to climate change is, to a large extent, about how well the diverse and growing water scarcity and water pollution challenges, exacerbated by climate change as outlined above, are dealt with.

3.2 Options to enhance water security under a changing climate

3.2.1 Innovations in and adaptation of conventional water infrastructure

As section 3.1.2 suggests, climate change challenges conventional water infrastructure solutions. More emphasis on multi-purpose infrastructure projects may partially help meet the challenge (Branche, 2015). Such projects often address drought resistance, flood control, regional development and other needs conjunctively and yet provide public goods (navigation, river basin management, maintaining 'ecological' river flows, etc.), recognizing the cross-sectoral and multi-purpose nature of water. Nature-based solutions (NBS) can be implemented to better adapt to climate change, to increase the efficiency, effectiveness and robustness of water management infrastructure (including operations and maintenance), and to contribute to climate change mitigation.

As a conventional approach to surface water storage, the potential for building more reservoirs, particularly large ones, is increasingly limited by siltation, available runoff, environmental concerns and restrictions, and the fact that most cost-effective and viable sites – at least in developed countries – have been already used. While it is unlikely that NBS can replace some larger forms of built storage infrastructure, more ecosystem-friendly forms of water storage, such as natural wetlands, soil moisture retention (through sustainable land management) and more efficient groundwater recharge (Section 3.2.2) could help enhance the overall effectiveness of surface storage operations (WWAP/UN-Water, 2018). It is important to identify the most appropriate blend of conventional infrastructure and NBS. An example is to apply more water harnessing upstream for release for human use and environmental flows, while using treated wastewater for managed aquifer recharge (MAR) in coastal areas to combat seawater intrusion and reuse for urban purposes. Application of such hybrid approaches could expand rapidly if water resources and land use planning policy and management consider these NBS and increase investments. Evidence suggests that investment in NBS remains well below 1% of total investment in water resources management infrastructure (WWAP/UN-Water, 2018).

The increasing impacts of climate change and other change drivers trigger the need for overall revision of national and regional storage operation, planning and management strategies (Scanlon and Smakhtin, 2016), including in some countries, like the USA, with a long history of large storage development (Ho et al., 2017). In the past, ecological impacts of infrastructure development and future costs such as maintenance or removal beyond the economic design life were not fully considered or valued. Progressively, legislation becomes stronger, giving more value to ecology and environmental considerations. Increasing impacts of climate change trigger the need to develop various innovations in water storage – in a variety of ways (e.g. Box 3.1; WWAP/UN-Water, 2018, Box 2.1, p. 39).

Enhancing the resilience of WASH infrastructure is particularly critical in Least Developed Countries (LDCs) and Small Island Developing States (SIDS), where vulnerability to climate change impacts is relatively high. According to the World Health Organization (WHO, 2015a), adaptation and resilience measures for sanitation systems to counteract climate change should be implemented under six categories, including technologies and infrastructure, financing, policy and governance, workforce, information systems, and service delivery. Table 3.1 (WHO, 2018a) summarizes possible adaptation measures for some key sanitation technologies and sanitation management systems.

Overall, conventional water infrastructure is becoming more vulnerable to climate change, and may incur increasingly high costs or adverse societal and environmental impacts. On the other hand, lack of water infrastructure of any kind makes a country even more vulnerable to changing hydrological regimes. In countries with economic water scarcity, more water infrastructure, like water storage and reliable water supply and sanitation systems, needs to be developed in an accelerated way, but with a clear consideration of future climate uncertainty and (generally increasing) variability.

Table 3.1 Examples of climate adaptation options for specific sanitation systems

Sanitation system	Potential impact	Example adaptation options	Overall resilience
On-site systems			
Dry and low-flush toilets	• Reduced soil stability leading to lower pit stability • Environmental and groundwater contamination from toilet flooding • Toilet owners using floodwaters to flush out pits • Toilet collapse due to inundation or erosion	• Line pits using local materials • Locally adapted toilet designs: raised toilets; smaller, frequently-emptied pits; vault toilets; raised pit plinths; compacting soil around pits; appropriate separation distances; use of appropriate groundwater technologies; protective infrastructure around system • In highly vulnerable areas: low-cost temporary facilities • Site systems in locations less prone to floods, erosion, etc. • Provide regular, affordable pit emptying services • Dispose excreta to secure sewer discharge or transfer stations • Promote toilet maintenance, hygiene and safe behaviours during/after extreme events	High (Good adaptive capacity through potential design changes)
Septic tanks	• Increased water scarcity reducing water supplies and impeding tank function • Rising groundwater levels, extreme events and/or floods, causing structural damage to tanks, flooding drain fields and households, tank flotation, environmental contamination	• Install sealed covers for septic tanks and non-return valves on pipes to prevent back flows • Ensure vents on sewers are above expected flood lines • Promote tank maintenance, hygiene and safe behaviours during/after extreme events	Low to medium (Some adaptive capacity; vulnerable to reduced water availability and flooding of combined sewers)
Off-site systems			
Conventional sewerage (e.g. combined sewers and gravity sewers)	• Extreme rainfall events causing discharge of excess, untreated wastewater into environment • Extreme rainfall events causing back-flooding of raw sewage into buildings • Extreme events damaging sewers and causing leakage, resulting in environmental contamination • Sea-level rise raising water levels in coastal sewers, causing back-flooding • Increased water scarcity reducing water flows in sewers, increasing solid deposits and blockages	• Use deep tunnel conveyance and storage systems to intercept/store combined sewer overflow • Re-engineer to separate stormwater flows from sewage • Where feasible, decentralize systems to localize/contain impacts • Provide additional storage for stormwater • Use special gratings and restricted outflow pipes • Install non-return valves on pipes to prevent back flows • Where appropriate, install small-bore or other low-cost options to reduce costs of separate systems • Promote hygiene and safe behaviours during/after extreme events	Low to medium (Some adaptive capacity; vulnerable to reduced water availability and flooding of combined sewers)

Sanitation system	Potential impact	Example adaptation options	Overall resilience
Off-site systems (continued)			
Modified sewerage (e.g. small-bore and shallow sewers)	• Floods and extreme events damaging sewers, especially shallow sewers • Small-bore sewers: damage to pipework infrastructure introducing soil to system and causing solid deposits/ blockage risks • Shallow sewers: increased water scarcity reducing water flows in sewers, increasing solid deposits and blockages	• Install non-return valves on pipes to prevent back flows • Construct simplified sewer networks to withstand flooding and flotation, or shorter networks connected to decentralized treatment facilities to reduce sewer overload and failure • Promote hygiene and safe behaviours during/after extreme events	Medium (Some adaptive capacity; vulnerable to flooding, though less vulnerable to reduced water availability than conventional sewerage)
Faecal sludge treatment	• Extreme weather events or floods destroying/damaging wastewater treatment systems, causing discharge of untreated sewage and sewerage overflow and environmental contamination • Extreme rainfall damaging waste stabilization ponds • Extreme events damaging low-lying treatment plants, causing environmental contamination • Increased water scarcity causing obstruction, reducing capacity in rivers or ponds that receive wastewater	• Install flood, inundation and runoff defences (e.g. dykes) and undertaking sound catchment management • Invest in early warning systems and emergency response equipment (e.g. mobile pumps stored off-site, non-electricity based treatment systems) • Prepare a rehabilitation plan for the treatment works • Where feasible: site systems in locations less prone to floods, erosion, etc. • Provide safe means for manual emptying of sludge with low moisture content	Low to medium (Some adaptive capacity; vulnerable to increases/ decreases in water availability; reduced carrying capacity may increase sludge treatment requirements)

Source: Adapted from WHO (2018a, table 3.6, pp. 54–56).

3.2.2 Groundwater storage and conjunctive water management

In many regions of the world, aquifers represent the largest source, or potential source, of water storage, with often orders of magnitude more storage capacity than surface-water storage (Hanak et al., 2011). Because aquifers often span large geographic areas and regions, they provide a spatially distributed source of water and storage as well as some built-in water conveyance. Groundwater is also more buffered from seasonal and multi-year climate variability and less immediately vulnerable than surface water (Green et al., 2011).

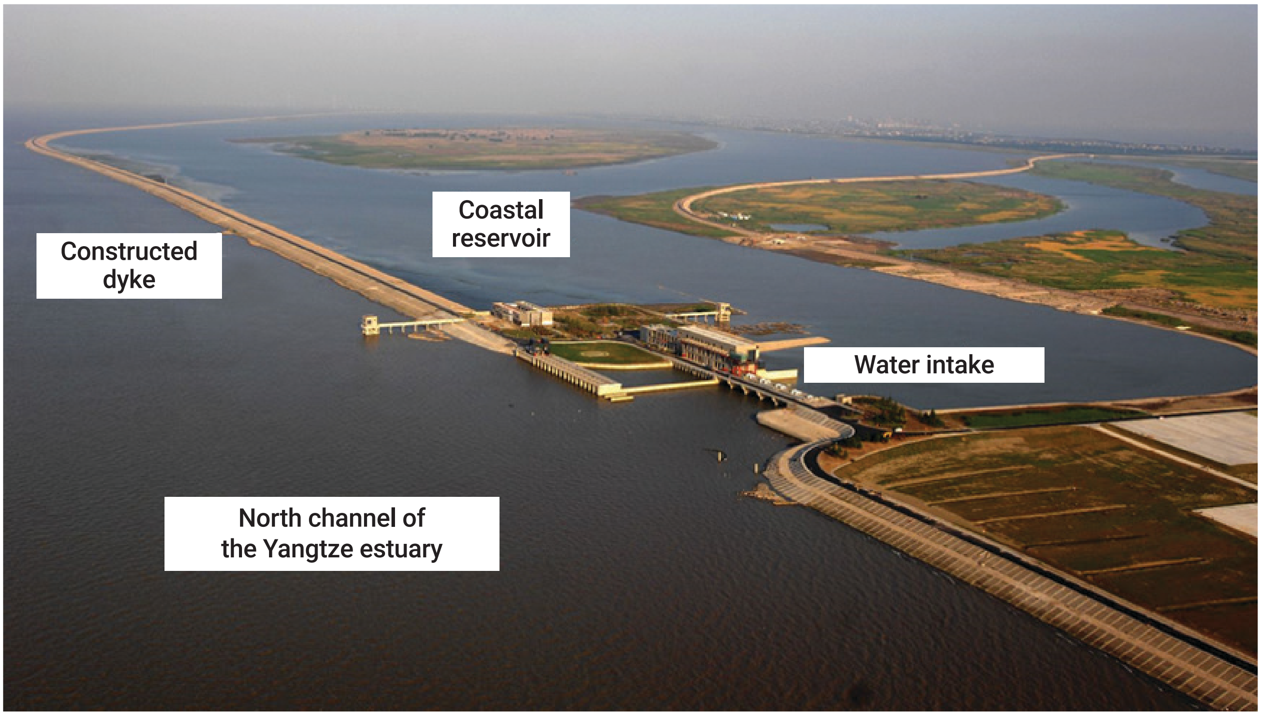
Shallow groundwater is generally more accessible by rural and poor communities than river flow because of the necessary infrastructure to harness and distribute the river water to dispersed rural communities. However, some regions, including much of Africa, lack infrastructure such as wells, technical capacity to build and maintain infrastructure, and hydrogeological characterization of aquifer systems to develop and sustainably use local groundwater resources and enhance water storage in local aquifers (UNESCO-IHP, 2015a; 2015b).

Aquifer storage includes not only groundwater already in aquifers but also the potential to store additional water, if it can be captured. MAR serves various purposes (Dillon et al., 2018; WWAP/ UN-Water, 2018; GRIPP, n.d.), including maximizing water storage, replenishing depleting aquifers, improving water quality, enhancing flood management, and mitigating seawater intrusion of coastal aquifers or land subsidence. MAR approaches can use water supplied by both conventional (typically surface water) and unconventional sources (e.g. reclaimed or desalinated water; see next Section), through integrated or ‘conjunctive use’ management strategies. The use of wastewater for MAR has been on the rise (GRIPP, n.d.).

Box 3.1 Coastal reservoirs as a water supply option for coastal cities

An emerging solution to the water supply problems of coastal megacities is the creation and use of coastal reservoirs, which provide water storage facilities at or near the mouth of rivers. Such storage is formed either by constructing a barrage across the river, or by containment reservoirs built along one of the riverbanks or the coastline. These reservoirs generally have a system of gates that are operated in a carefully designed manner to capture freshwater, reduce flood risk, and minimize saltwater intrusion. Many coastal cities, including Hong Kong, Shanghai and Singapore are using coastal reservoirs for their water supply. For example, the Qingcaosha Coastal Reservoir in the mouth of the Yangtze River, completed in 2010, supplies water to nearly 50% of Shanghai city residents (Lin et al., 2018). The construction of several coastal reservoirs in China has advanced their design and the overall best practices of this type solution. However, challenges such as saltwater intrusion, pollution control, algal blooms, sediment accumulation and ecosystem imbalances are important considerations for the design, construction and operation of coastal reservoirs. Coastal reservoirs as a supplement to local water supplies have been or are currently being explored in other countries, including India (Sitharam, 2018), Malaysia (Chong et al., 2018), the Netherlands and Australia (Yang and Ferguson, 2010), though the Netherlands already have strong historic experience and expertise in managing coastal waters. The coastal reservoirs can also provide renewable energy if they are in regions of high tidal range (Angeloudis et al., 2016).

Figure Aerial view of the Qingcaosha Coastal Reservoir at the mouth of the Yangtze River



Source: Adapted from Lin et al. (2018, fig. 12, p. 8).

While surface reservoirs have the potential to fill and empty quickly, creating a flexible water supply that also assists flood management, large surface storage is costly and may be ecologically damaging (Hanak et al., 2011). Aquifers recharge and empty more slowly, which makes them more suitable for longer-term storage. Conjunctive use, taking advantage of a span of storage solutions, makes it possible to expand a region's overall water storage capacity, by using more surface water (and storing more water in aquifers) during wet periods, and relying on groundwater during dry periods.

Groundwater is underutilized is some regions, such as parts of Africa and Central Asia. Still, an estimated 75% of Africans use groundwater for small-scale purposes, namely as their main source of drinking water, particularly in rural areas that rely on dug wells and boreholes (Tuinhof et al., 2011). However, only about 1% of the cultivated land in Africa is irrigated with groundwater, and for the most part this resource remains an underutilized and reliable resource for irrigated food production (Altchenko and Villholth, 2015). Many other regions, including parts of the USA, China and the Indo-Gangetic plains of northern

India, suffer from over-abstraction of groundwater resources, which has resulted in severe drawdown of the water tables (Tiwari et al., 2009; Wada et al., 2010; Famiglietti, 2014; Richey et al., 2015). Climate change may exacerbate such phenomena as higher air temperature, resulting in an increase in evaporation of rainfall and therefore reduced recharge (Taylor et al., 2012).

Groundwater recharge may also be impacted by climate change in other ways: in arid and semi-arid areas, the increased intensity of rainfall associated with and amplified by climate change (see Box 9.2) may make groundwater recharge more episodic and localized (Cuthbert et al., 2019). An adequate management of surface water and groundwater through various forms of MAR has the potential to reduce the peak flood flows and inundations, and to mitigate the groundwater depletion at the same time (Muthuwatta et al., 2017).

Water storage is a particularly critical issue on low-lying islands, atolls and many SIDS. These are among the most vulnerable communities to climate change because of sea level rise, which has a direct impact on flood risk, but also reduces the size of groundwater lenses because of seawater intrusion. Proper management and use of groundwater will be important for sustaining access to supplies of potable water in many SIDS. The use of MAR has greatly increased in coastal aquifers worldwide to enhance water storage and in part to minimize seawater intrusion (GRIPP, n.d.). However, the use of MAR on atolls or SIDS is not widely reported (Hejazian et al., 2017). SIDS' adaptation to climate change will require more MAR programmes that recharge the freshwater lens from rainwater or stormwater capture during wet periods to help sustain communities through dry periods (UNESCO-IHP, 2015b).

3.2.3 Unconventional water resources

The growing demand for water, resulting from population growth and the need to produce more food, puts increasing pressure on the limited available water resources, particularly in areas of physical water scarcity. This is accentuated by the fact that improvements in the efficiency of exploiting conventional sources and approaches have a ceiling (World Bank, 2017a). It is increasingly necessary to consider various 'unconventional' and/or regionally underutilized water resources (Figure 3.1) as part of water management and water planning for the future (Qadir and Smakhtin, 2018). Unconventional water resources are generated as a result of specialized processes or technologies to collect/access water. They may require suitable pre-use treatment, potentially including on-farm management when used for irrigation (Qadir et al., 2007).

Figure 3.1 Examples of unconventional water resources/technologies

Used water/wastewater

Desalinated water

Atmospheric water capture (fog, cloud seeding)

Photo credits: Used water/wastewater: Manzoor Qadir (UNU-INWEH); desalinated water: modern desalination plant on the shores of the Arabian Gulf (summer 2016): © Stanislav71/Shutterstock.com; and atmospheric water capture: Rector Ignacio Sánchez (Pontificia Universidad Católica de Chile) visits Alto Patache: © Nicole Saffie, licensed under: CC BY-NC-SA 2.0.

Safe water reuse (or 'reclaimed water') is a reliable alternative to conventional water resources in the face of climate change impacts (WWAP, 2017). The main challenge remains in shifting from unplanned use of untreated, or partially treated, wastewater to safe water reuse practices. Use of untreated or poorly treated water is associated with human and environmental health risks linked to microbial and emerging pollutants in reclaimed water. Several countries, particularly in arid and semi-arid regions, use treated wastewater for irrigation. Water reuse in agriculture has been shown to act as a buffer to increasing water scarcity and the impacts of extreme climate events (Drechsel et al., 2015; Hettiarachchi and Ardakanian, 2016; WWAP, 2017). With more intense and prolonged droughts, a growing number of cities (e.g. in India and the USA) are adopting direct or indirect (via MAR) potable reuse schemes to cope with recurrent water shortages. In Namibia, the city of Windhoek has been successfully implementing potable reuse for over 50 years (Box 3.2). Reclaimed water is increasingly considered an alternative water resource in some regions of Europe. According to Water Reuse Europe (2018), only 2% of treated wastewater is reused in Europe, but it is expected to grow in the future, with the biggest potential in Portugal and Spain.

Seawater and brackish water desalination. Desalination is an option to augment freshwater supplies by removing dissolved salts from brackish or saltwater. According to the estimate by Jones et al. (2019), there are 16,000 operational desalination plants globally, producing around 95 million m^3/day of desalinated water, of which around 50% is produced in the Middle East and North Africa region. However, desalination is relatively costly due to high energy consumption – even if the cost is becoming increasingly competitive. The production and disposal of a hypersaline concentrate ('brine'), a process by-product, is another challenge in terms of costs and associated environmental impacts. Given the unlimited nature of seawater and the decreasing cost of renewable energy sources, desalination has a potential to significantly improve water supply in the future and may even replace domestic and industrial water demand in the 100-km coastal belt by 2050 (Sood and Smakhtin, 2014).

Atmospheric moisture harvesting such as cloud seeding, or fog water collection in areas where advective fog is abundant, is practiced in parts of South America, the Middle East and North America. Many locations with estimated high potential for fog water collection have been identified throughout the globe (Klemm, et al., 2012). Unlike the massive potential provided by desalination, fog water is primarily of local importance, as a low-cost and low-maintenance approach (Qadir et al., 2018).

Offshore aquifers. Attention is growing to offshore groundwater options. It is estimated that 0.5 million km^3 of fresh/brackish water exists in offshore aquifers located below shallow (<500 m) ocean water within 100 km of the shoreline (Post et al., 2013). There are multiple locations around the world where offshore low-salinity groundwater has been observed (Person et al., 2017). Post et al. (2013, p. 76), however suggest that "*offshore groundwater is not the answer to global water crises*", but "*…it can be weighed against other options in long-term strategies*".

Physical transportation of freshwater by the sea. These options are the most 'fictional' at present, but the ideas and attempts to harvest them are becoming stronger (Rafico, 2014). Water can be transported from large rivers' deltas/estuaries, such as Amazon or Congo (the total annual discharge of both is close to 8,000 km^3, some 20 times the total amount of wastewater globally) by tankers or bags to such areas as

Box 3.2 Fifty years of direct potable reclamation in Windhoek, Namibia

For over 50 years, the City of Windhoek has been directly reclaiming potable water from secondary effluent. Direct Potable reclamation has proven to be a safe and economically feasible way to supplement the scarce water resources in Windhoek and to overcome the effects of reoccurring droughts (Du Pisani et al., 2018). The current supply of drinking water to the approximately 400,000 inhabitants of the City of Windhoek consists for 25–30% of reclaimed water (Lahnsteiner and Lempert, 2007).

In the absence of existing legislation, regulations, policies or guidelines on the subject, the City of Windhoek decided to use an approach centred on consumer safety when implementing direct potable reclamation (Law et al., 2015). This experience resulted in an acceptance and trust towards this non-conventional source of drinking water (Boucher et al., 2010).

The capacity of the first reclamation plant commissioned in 1968 was 4,800 m^3/day, which was over the years adapted in terms of processes applied. Its capacity was then increased to 7,200 m^3/day (1986) and later to 14,400 m^3/day (1994). The newest reclamation plant, commissioned in 2002, has a capacity of 21,000 m^3/day (Honer, 2019).

Contributed by AquaFed.

Cape Town, which almost ran out of water during the recent drought of 2017–2018 (Schreiber, 2019). Assessments exists of the possibility to transport water from far-apart water-abundant places to water-scarce regions such as Namibia and South Africa (Valentine, 2017). Similarly, the ideas for iceberg transport – either as a whole or 'shaved ice' in tankers have been put forward (Ruiz, 2015). These options at present exist only as concepts due to their high cost, large fleet of tankers required and large calculated losses.

Atmospheric moisture harvesting such as cloud seeding, or fog water collection in areas where advective fog is abundant, is practiced in parts of South America, the Middle East and North America

The production and/or use of some of the unconventional water resources such as desalinated water or wastewater may result in environmental impacts and/or associated health risks. Hence, these different options for unconventional water resources need health and environmental risk assessments and pertinent mitigation options (Grangier et al., 2012; WWAP, 2017; Qadir, 2018; Jones et al., 2019). Some unconventional sources, like water reuse, increase resilience to climate change through renewable energy generation, for example energy recovery from wastewater during the treatment process (Drechsel et al., 2018).

In summary, in the face of climate change, water supply augmentation using unconventional sources offer alternative solutions to increase water supplies to meet the growing water demand, especially in regions and countries with physical water scarcity. At present, among unconventional water resources, reclaimed water is seen as being the most promising with a growing number of successful real-life applications and a worldwide growing market for reclaimed water, particularly for irrigation. To increase wastewater reuse in agriculture and other sectors, effective monitoring and regulations need to be developed and implemented to overcome concerns related to environmental and human health risks. Applications of other unconventional water sources and technologies will likely continue grow in the next decades.

3.3 Mitigation options for water resources management[5]

3.3.1 The water supply and sanitation sector

The bulk of the greenhouse gas (GHG) emissions related to water management and sanitation either originates from 1) energy used to power the systems and 2) the biochemical processes involved in water and wastewater treatment.

Water and wastewater utilities are reportedly responsible for between 3 and 7% of GHG emissions (Trommsdorf, 2015), but these estimates do not include emissions associated with discharging untreated sewage. Indeed, untreated wastewater is an important source of GHGs. Given that, in developing countries, 80–90% of the wastewater is neither collected nor treated (Corcoran et al., 2010; WWAP, 2017), the emissions related to the water supply and sanitation sector – and its potential to contribute significantly to climate change mitigation – should not be neglected.

Electricity use by the sector is mainly for the abstraction (40%), conveyance (25%) and treatment (20%) of water and wastewater, representing some 4% of global electricity production. Energy consumption in the water sector is expected to double through 2040, as a result of increasing desalination of seawater (Figure 3.2; IEA, 2016). Energy consumption for wastewater treatment is also expected to increase in the coming decades, which seems unnecessary since, at the global scale, the potential for energy-positive treatment plants has been increasing rapidly (Freyberg, 2016). Increasing water use efficiency and reducing unnecessary water consumption and water loss both translate into lower energy use and thus lower GHG emissions. It has been estimated that the water sector worldwide could reduce its energy use by 15% until 2040 (IEA, 2016).

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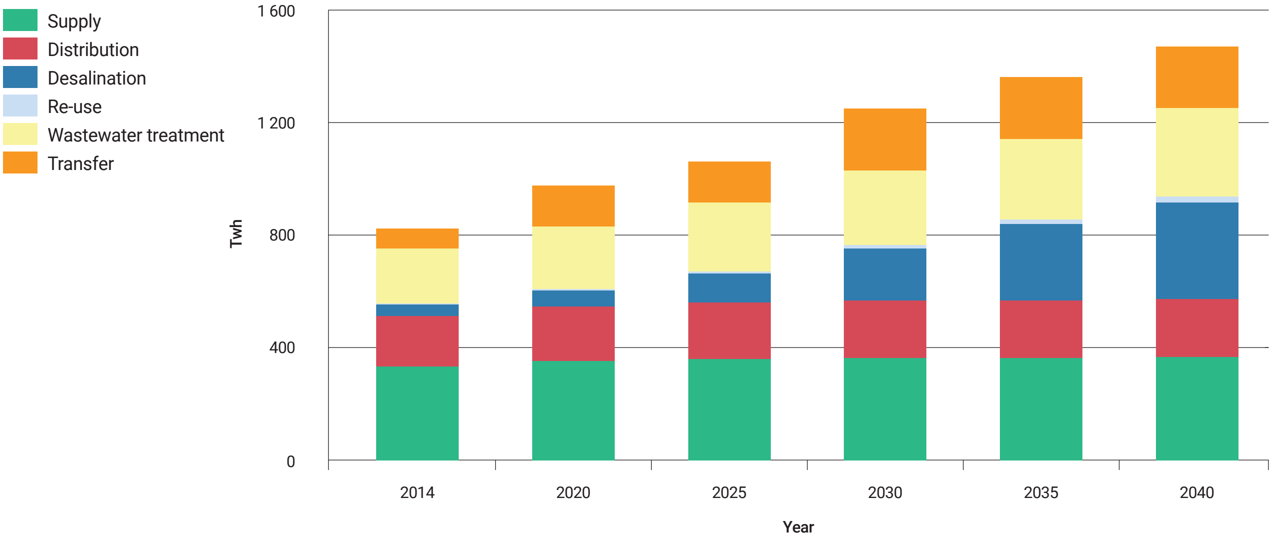
[5] This section draws heavily on an advanced draft of the report *Stop Floating, Start Swimming: Water and Climate Change – Interlinkages and Prospects for Future Action* (GIZ/adelphi/PIK, forthcoming).

Figure 3.2 Electricity consumption in the water sector by process, 2014–2040



Source: IEA (2018). All rights reserved.

The formation of CH_4 and N_20 in landfills, open sewers and lagoons amounted to an estimated 13% of global non-CO_2 emissions in 2005 (US EPA, 2012). Some 58% of these emissions stem from landfills, part of which is wastewater treatment sludge disposal (Guo et al., 2012). The contribution of non-CO_2 emissions from wastewater is expected to increase (US EPA, 2012).

The organic matter in wastewater contains more energy than is needed to treat it (Li et al., 2015). Energy from wastewater can therefore be an important source for the water sector to become more energy-efficient. Centralized treatment plants capture most of the developing CH_4 and use this for energy production, thus reducing both direct emissions and indirect emissions from energy use. Some wastewater treatment facilities in Europe and the USA have on-site renewable energy production and energy use efficiency improvements, leading to advancements in 'net-zero' energy and energy-positive practice (Rothausen and Conway, 2011; Maktabifard et al., 2018).

Wastewater can be a source of raw materials like nutrients or certain metals (i.e. industrial wastewater), further contributing to reduced energy required in the extraction of these raw materials for use as fertilizers (Wang et al., 2018a).

Thus, by increasing water use efficiency and by reducing water losses, including reuse of (untreated or partially treated) wastewater and its constituents, water supply and sanitation systems can not only directly and substantially contribute to GHG mitigation, but also become more cost-effective.

In addition to wastewater treatment infrastructures, an overlooked source of non-CO_2 emissions are dam reservoirs (World Bank, 2017b). CH_4 emissions caused by the decomposition of organic material in dam reservoirs may contribute as much as 1.5% of global CO_2-equivalent emissions, a number that may rise due to new dam construction in certain parts of the world (Zarfl et al., 2016) and increasing erosion due to land use change and unsuitable land management practices. Moreover, increases in wastewater discharge and fertilizer-rich runoff can lead to enhanced levels of eutrophication. The resulting methane emissions from lakes and reservoirs alone are estimated to increase by 30–90% through 2100 (Beaulieu et al., 2019).

Innovative use of water infrastructure can also be a source of energy. For instance, gravity-driven pipelines for drinking water may be equipped with turbines to generate electricity. Vienna's drinking water, for example, comes from mountain springs through two long-distance pipelines. The turbines that are installed, in addition to producing electricity, reduce the water pressure to levels suitable for the city's drinking water infrastructure (WWAP, 2014).

Tunnel on a water infrastructure project in Washington, D.C.

3.3.2 Water-related ecosystems

Wetlands,[6] including peatlands, accommodate the largest carbon stocks among terrestrial ecosystems and store twice as much carbon as forests (Crump, 2017; Moomaw et al., 2018). Wetlands are however under high pressure, and the loss rate of wetlands is three times higher than that of forests (Ramsar Convention on Wetlands, 2018). A poorly managed wetland can become a source of GHGs instead of a sink. Peatland, for instance, consists of a thick layer of peat, a carbon stock that has formed over thousands of years. Draining peatland for agriculture or other purposes leads to decomposition of the peat, releasing CO_2 and other GHGs into the atmosphere (see Chapters 6 and 9). The carbon stock is reduced as a consequence. In 2017, around 15% of the global peatlands were considered to be either degraded or destroyed, with agriculture being the main driver. Burnt and drained peatlands account for nearly 5% of the global CO_2 emissions caused by humans (Crump, 2017). On top of this, wetlands are sensitive to global warming; warmer climates could lower the rate at which peatlands accumulate carbon over the long term (Gallego-Sala et al., 2018).

Griscom et al. (2017) suggest that around a third of the GHG mitigation until 2030 can be attained through ecosystem-based mitigation, to which wetlands can contribute a share of 14%. Taking into account that wetlands offer multiple co-benefits – including flood and drought mitigation, water purification, and biodiversity – conservation of wetlands is an important mitigating measure.

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[6] A wetland is a distinct ecosystem that is inundated by water, either permanently or seasonally, where oxygen-free processes prevail. The main wetland types are swamp, marsh and peatlands (bog and fen), and also include mangroves and seagrass meadows (Keddy, 2010).

4

Water-related extremes and risk management

Flood in Venice on 12 November 2019 (Italy).

UNU-INWEH | Duminda Perera and Vladimir Smakhtin

With contributions from: Frederik Pischke (GWP); Miho Ohara (ICHARM); Angelos Findikakis (IAHR); Micha Werner (IHE Delft); Giriraj Amarnath (IWMI); Sonja Koeppel and Hanna Plotnykova (UNECE); Stephan Hülsmann (UNU-FLORES); and Claudio Caponi (WMO)

This chapter focuses on the linkages between climate change adaptation and disaster risk reduction, highlighting opportunities to build more resilient systems through a combination of 'hard' and 'soft' measures.

4.1 Climate and water extremes as challenges for water management

Climate change manifests itself, amongst others, through increasing frequency and magnitude of extreme events such as heat waves, unprecedented rainfalls, thunderstorms and storm surge events caused by cyclones, typhoons or hurricanes, that, in turn, render societies increasingly vulnerable to water-related disasters. Around 74% of all natural disasters between 2001 and 2018 were water-related and during the past 20 years, the total number of deaths caused only by floods and droughts exceeded 166,000, while floods and droughts affected over three billion people, and caused total economic damage of almost US$700 billion (EM-DAT, 2019).[7] The number of deaths, people affected and economic losses significantly varies annually and by continent, with Asia and Africa being the most impacted on all counts (Figures 4.1, 4.2, 4.3).

The current impacts and future anticipated risks associated with extreme events demand sustainable solutions for climate change adaptation and disaster risk reduction

Climate change has made extreme events more severe by altering the timing, intensity and duration of their occurrences (Blöschl et al., 2017). For example, in certain cases it has caused droughts in the winter months, which may cause much greater impacts on agricultural and water resource systems than in the summer (FAO, 2018b). The current impacts and future anticipated risks associated with extreme events demand sustainable solutions for climate change adaptation (CCA) and disaster risk reduction (DRR). CCA and DRR are connected through the common goal of reducing the impacts of climate change, minimizing the consequences of extreme events when they happen and increasing resilience to disasters, particularly among vulnerable communities in developing countries and Small Island Developing States (SIDS).

Protection of human rights during extreme events is essential as these events can trigger political, social and economic instabilities in countries, degrading health, livelihoods, and food and water security. The currently active Sendai Framework (see Section 2.2.3) is a critically important international effort that aims to make the world much safer in 2030, through seven targets and four priorities timely designed for DRR (UNDRR, 2015a).

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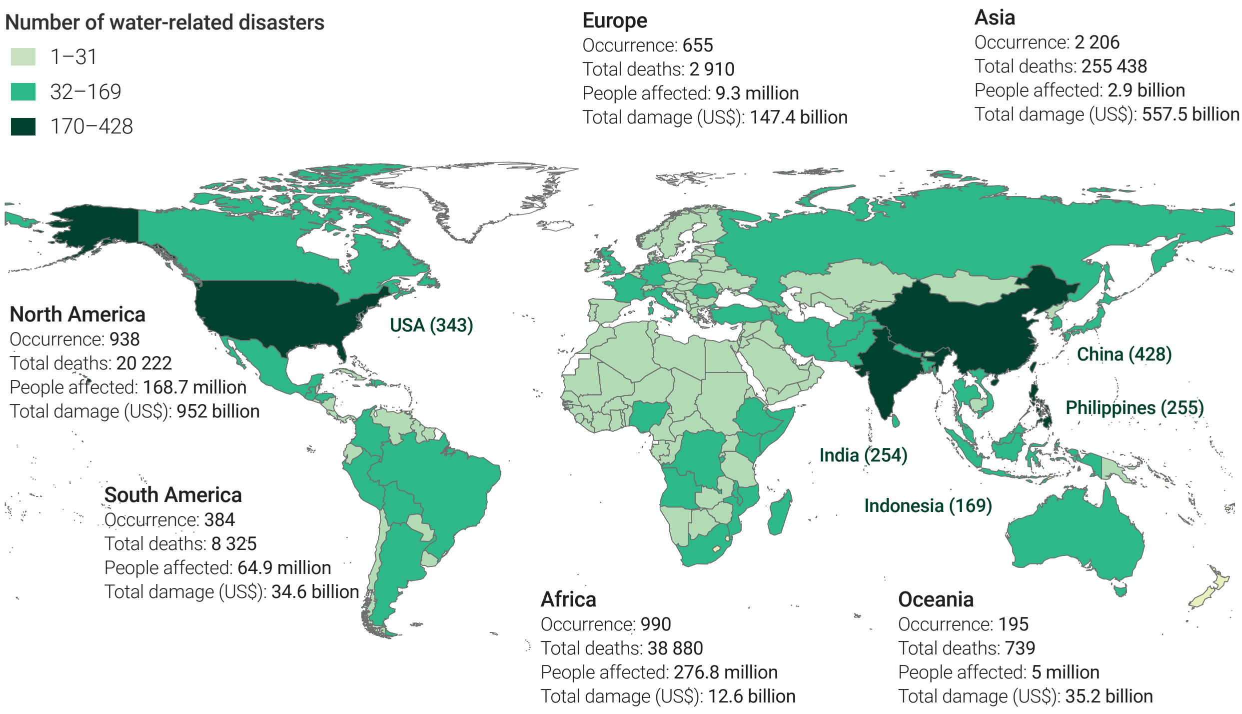
[7] CRED's Emergency Events Database (EM-DAT) is used here to provide global, continental, national or regional disaster statistics.

Figure 4.1 Spatial distribution of water-related disasters (droughts, floods, landslides and storms), 2001–2018



Europe
Occurrence: 655
Total deaths: 2 910
People affected: 9.3 million
Total damage (US$): 147.4 billion

Asia
Occurrence: 2 206
Total deaths: 255 438
People affected: 2.9 billion
Total damage (US$): 557.5 billion

North America
Occurrence: 938
Total deaths: 20 222
People affected: 168.7 million
Total damage (US$): 952 billion

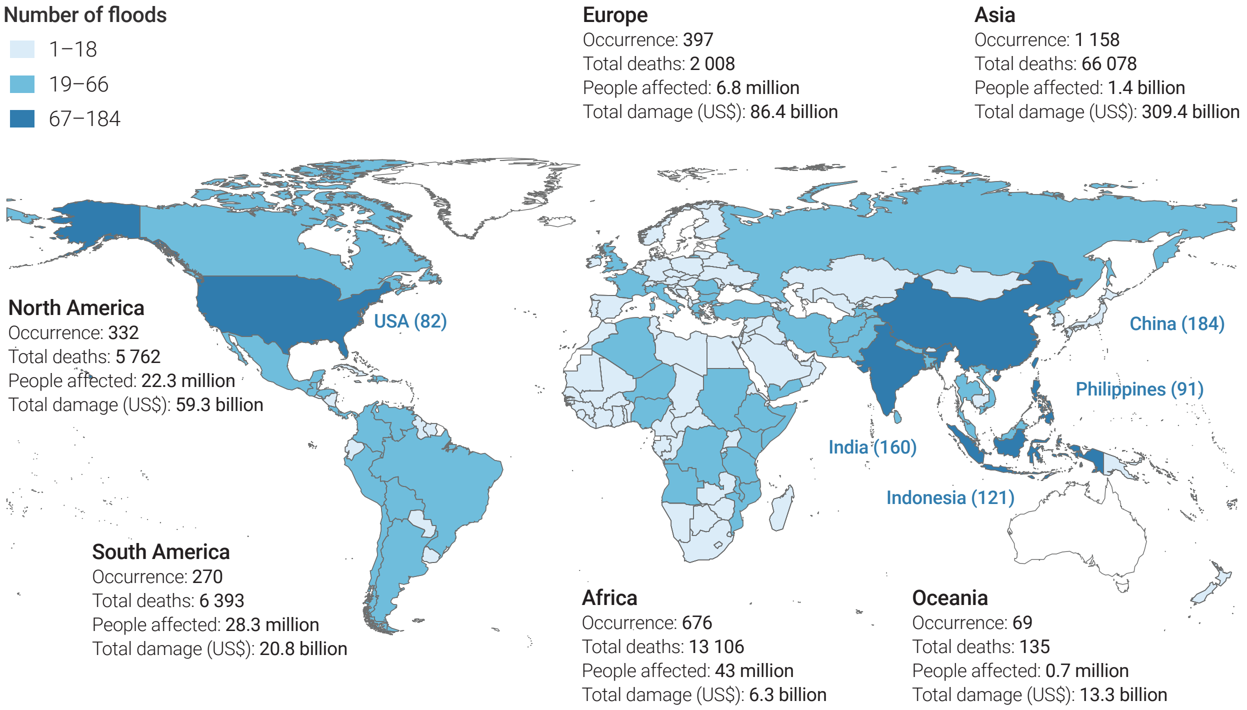
South America
Occurrence: 384
Total deaths: 8 325
People affected: 64.9 million
Total damage (US$): 34.6 billion

Africa
Occurrence: 990
Total deaths: 38 880
People affected: 276.8 million
Total damage (US$): 12.6 billion

Oceania
Occurrence: 195
Total deaths: 739
People affected: 5 million
Total damage (US$): 35.2 billion

Source: Developed by UNU-INWEH, based on EM-DAT data.

Figure 4.2 Spatial distribution of floods, 2001–2018



Europe
Occurrence: 397
Total deaths: 2 008
People affected: 6.8 million
Total damage (US$): 86.4 billion

Asia
Occurrence: 1 158
Total deaths: 66 078
People affected: 1.4 billion
Total damage (US$): 309.4 billion

North America
Occurrence: 332
Total deaths: 5 762
People affected: 22.3 million
Total damage (US$): 59.3 billion

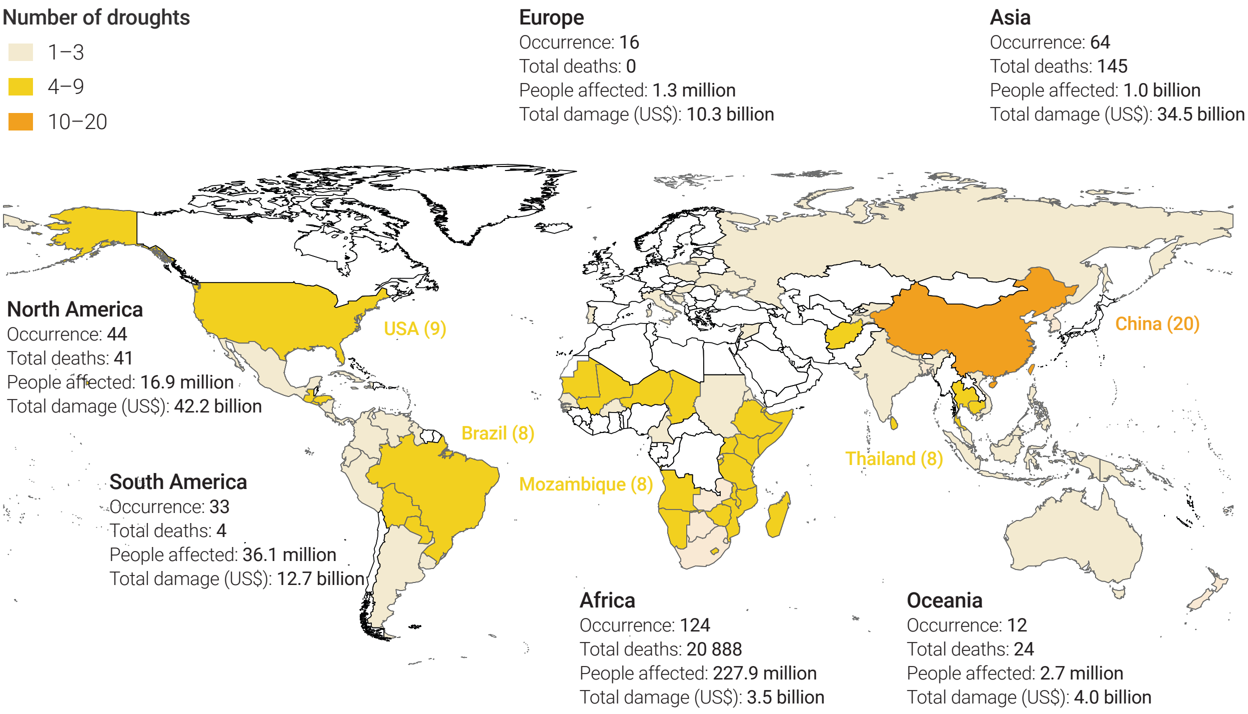
South America
Occurrence: 270
Total deaths: 6 393
People affected: 28.3 million
Total damage (US$): 20.8 billion

Africa
Occurrence: 676
Total deaths: 13 106
People affected: 43 million
Total damage (US$): 6.3 billion

Oceania
Occurrence: 69
Total deaths: 135
People affected: 0.7 million
Total damage (US$): 13.3 billion

Source: Developed by UNU-INWEH, based on EM-DAT data.

Figure 4.3 Spatial distribution of droughts, 2001–2018



Source: Developed by UNU-INWEH, based on EM-DAT data.

4.2

Hard and soft measures in climate change adaptation and disaster risk reduction

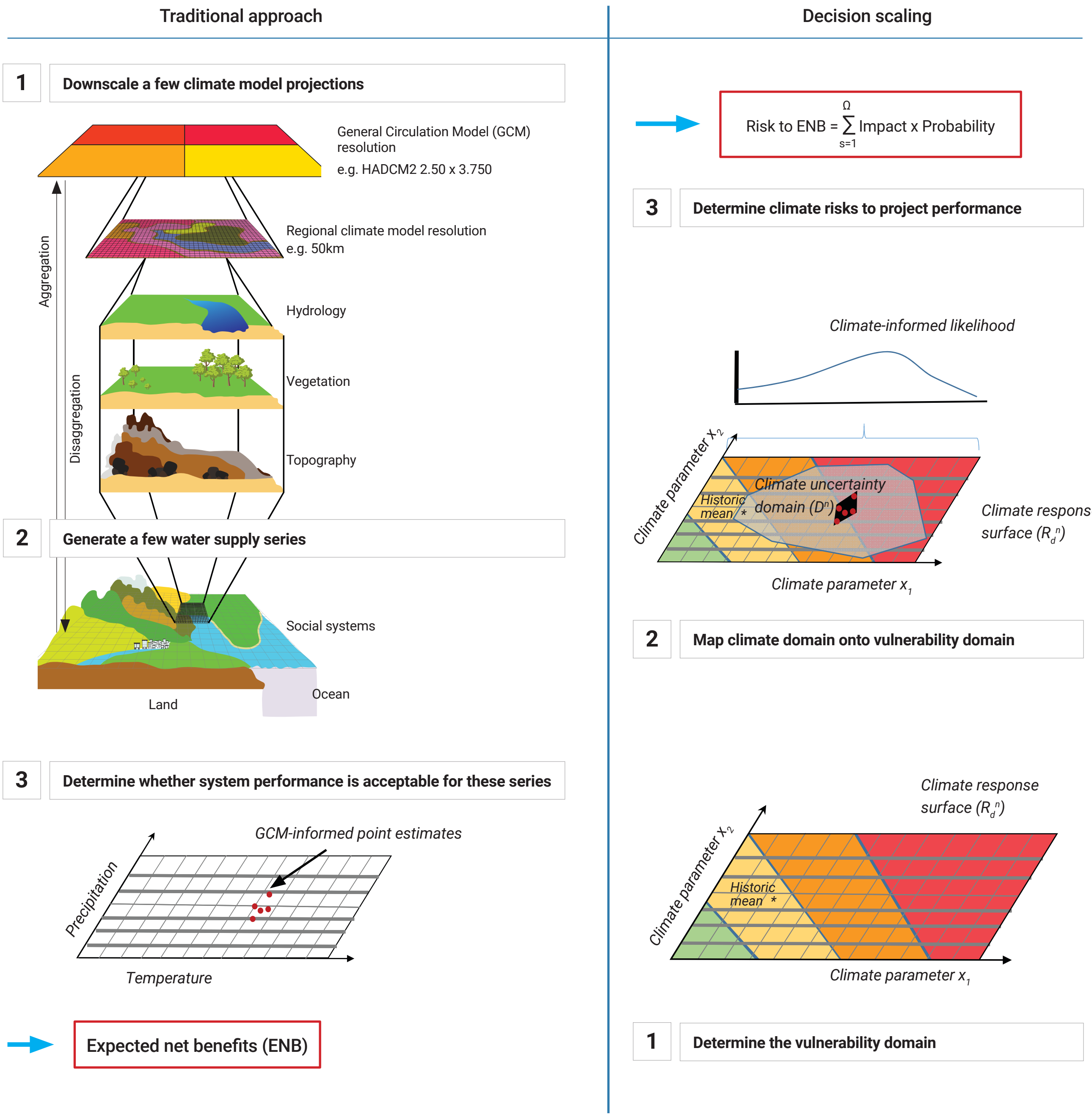
The range of available CCA and DRR strategies that may help overcome the impacts from extremes is diverse and includes hard (structural) and soft (policy instruments) approaches. Examples of hard measures include enhanced water storage, climate-proof infrastructure, and crop resilience improvements through the introduction of flood- and drought-resistant crop varieties. Examples of soft measures include flood and drought insurance, forecasting and early warning systems, land use planning, and associated capacity building (education and awareness) in all of the above. Hard and soft measures often go together. For example, implementing structural flood protection measures, or improvements to agricultural systems such as crop diversification or the introduction of hazard-resistant crop varieties (i.e. both, essentially, hard measures), need enabling policy environments (i.e. soft measures in the form of policy and institutional support).

4.2.1 Hard measures

Climate-proof infrastructure

Climate-proofing refers to the explicit consideration and internalization of the risks and opportunities that alternative climate change scenarios are likely to imply for the design, operation and maintenance of infrastructure, including water infrastructure under extreme events (UNDP, 2011). Conducting a disaster risk assessment is the essential first step in a DRR strategy and normally includes three elements: the magnitude of the *hazard* expressed in terms of frequency and severity (depth, extent, duration and relative velocities); the *exposure* of human activities to hazard; and the *vulnerability* of the elements at risk (APFM, 2007). Bottom-up climate assessments investigate exposure, the vulnerability of individuals and/or communities to climate variability, and the adaptive capacity for describing risks (García et al., 2014). In contrast, top-down approaches rely on climate models to predict a possible future and build their responses on the output of these models (Figure 4.4). Although both approaches can be used in a complementary fashion, often only one of the two is used. A policy guidance for conducting national disaster risk assessments and establishing a thorough understanding of risk systems is provided by the UN Office for Disaster Risk Reduction (UNDRR, 2017).

Figure 4.4 Top-down vs bottom-up climate risk assessment



Source: García et al. (2014, fig. 3.2, p. 19).© World Bank. openknowledge.worldbank.org/handle/10986/21066. Licensed under: CC BY 3.0 IGO.

Smart and adaptable approaches to water-related infrastructure such as dams, diversions, levees and drainage systems development are cognizant that the past is an unreliable guide to face present and future extreme events, due to the uncertainty caused by climate change. Among the water-related infrastructure that needs to be climate-proofed are dams. While storing water for periods of scarcity is often the main concern, increasing the capacity for absorbing floods can be equally important – with potentially conflicting management implications of both functions. To better deal with the increasing variability of river flows, various measures can be implemented, ranging from generally lowering the reservoir water level, to increasing flood retention capacities (Sieber and Socher, 2010), to increasing the (technical) capacity for water withdrawal within dams. This allows for more efficient lowering of water levels in case of an expected flood event. Adding outlet structures at various depths also enhances options to use them for water quality management by withdrawing, under stratified conditions, water from problematic water layers (Klapper, 2003). Such measures should be accompanied by measures in the drainage basin upstream of reservoirs.

Nature-based solutions
"*Nature-based solutions (NBS) are inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water*" (WWAP/UN-Water, 2018, p. 2). NBS include adapted land use to increase water storage capacities in the subsurface, preventing erosion and excessive overland flow, but also technical measures such as the construction of pre-dams (Paul and Pütz, 2008). Ecosystem-based adaptation (EbA) is particularly relevant for CCA and DRR, since it uses biodiversity and ecosystem services as part of an overall adaptation strategy to overcome the adverse effects of climate change and extreme events (IUCN, 2017). EbA could be implemented through maintaining and restoring ecosystems to a good ecological state, using ecosystems as naturally 'engineered' landscapes to help in DRR under climate change, and integrating CCA measures into wetlands and other ecosystem management strategies and plans and vice versa (UNECE/UNDRR, 2018).

4.2.2 Soft measures

Forecasting and early warning systems
Awareness and preparedness are fundamental components of resilience, DRR and response to water-related disasters. Early warning systems play an important role in DRR, especially to assess imminent flood and drought risks, enhance decision-making strategies, improve community preparedness, and mitigate damage from extreme events through timely and effective action. UNDRR (n.d.) defines early warning systems as "*an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enable individuals, communities, governments, businesses and others to take timely actions to reduce disaster risks in advance of hazardous events*".

Thanks to major improvements over the last decades in climate- and weather-related forecasting and prediction tools, communities at risk can currently often be provided with sufficient lead time to respond to imminent disasters (WMO, 2015a; 2015b; 2016). The timescales at which forecasts are provided are often divided into now-casting, with lead times in the order of 0–6 hours; short term forecasts (0–3 days); medium range forecasts (3–15 days); and the longer term sub-seasonal (1–3 months) to seasonal forecasts (3–6 months) (Golding, 2009). While smaller timescales lead to more accuracy, the choice of the most appropriate timescale is often concomitant with the decision processes that the forecasts provided intend to inform. In the example of informing responses to flash floods, now-casts and short-range forecasts are the appropriate timescale, while decision processes defined in drought management plans may be supported by forecasts at the sub-seasonal to seasonal scale.

Modern communication methods such as social media and mobile phone services provide significant opportunities to help improve communication and early warning effectiveness

Increasing lead times can help improve the effectiveness of early warning systems, but needs to be complemented with clear communication, and co-development and engagement with the communities at risk (Parker and Priest, 2012; Cools et al., 2016), especially in transboundary basins where coordination, cooperation and data sharing are sometimes limited due to political conflicts and weak governances within and between countries (Bakker, 2009a; 2009b). Modern communication methods such as social media and mobile phone services provide significant opportunities to help improve communication and early warning effectiveness (Cumiskey et al., 2015) (see Chapter 13). There are also increasing efforts to go beyond the hazard-only information traditionally provided by early warning systems, through the development of impact-based forecasting (WMO, 2015b). Rather than providing only predictions of hydro-meteorological variables, impact-based forecasts also aim to provide clear, sector-specific information on the expected impacts of extreme events. Similarly, action-based forecasting initiatives such as forecast-based financing (Coughlan de Perez et al., 2016) are being used to inform humanitarian response. Sustainable economic and social development requires prediction, forecasting and warning systems for communities at risk to be continuously developed, reviewed and refined, which in turn demands an optimal combination of data, forecasting tools and well-trained specialists and must be complemented by accurate risk management actions (Leonard et al., 2007). Integrating gender in early warning systems is important, as women and children are reportedly 14 times more likely than men to die during a disaster (UNDP, 2013). They also play a pivotal role in emergency preparedness and responses as well as in DRR (UNDRR, 2015b), provided they are empowered to do so.

Operational forecasting and warning services have been in development over several decades, providing many examples (Pappenberger et al., 2015; Adams and Pagano, 2016; Smith et al., 2017). These include services provided at the basin scale and national scale (an overview of several such systems can be found in Adams and Pagano, 2016) through to the continental and even global scale (Emmerton et al., 2016). However, a globally consistent picture is currently missing regarding the availability and state of operational early warning systems for floods, especially with regard to achieving the goals set in global agendas such as the Sendai Framework and the Sustainable Development Goals (SDGs) (Perera et al., 2019). There are also many technical, financial, institutional and social challenges, including inadequate hydro-meteorological networks, lack of technical expertise and limited human resources to perform forecasts, and lack of knowledge about operational effectiveness of early warning systems, among others.

Drought monitoring and drought early warning systems are similarly diverse and face similar challenges. Drought early warning systems, such as seasonal outlooks based on, for example, El Niño/Southern Oscillation (ENSO) indices, can be used to provide advance warning of drought conditions, or of continuing drought conditions, which in turn enable proactive drought management decision-making, such as destocking of animals, reduction in planted area, or planting of different crops. Seasonal drought forecasting has shown success in Southeast Asia and western South America (in large part due to their proximity to the Pacific Ocean, where the ENSO originates). However, the seasonal drought forecasts in Africa remain less precise. There are many examples of national and regional 'drought monitors' in operation (WMO/GWP, 2016).

In the drought management community, there has been a focus on advancing a three-pillar approach to drought management, incorporating: i) comprehensive drought monitoring and early warning systems; ii) vulnerability and impact assessments; and iii) appropriate drought risk mitigation and response actions (Pischke and Stefanski, 2018). The approach stresses the importance of interconnecting these three pillars through stakeholder engagement aimed at developing and implementing proactive drought management plans or policies.

Drought and flood monitoring systems are an important component of risk reduction

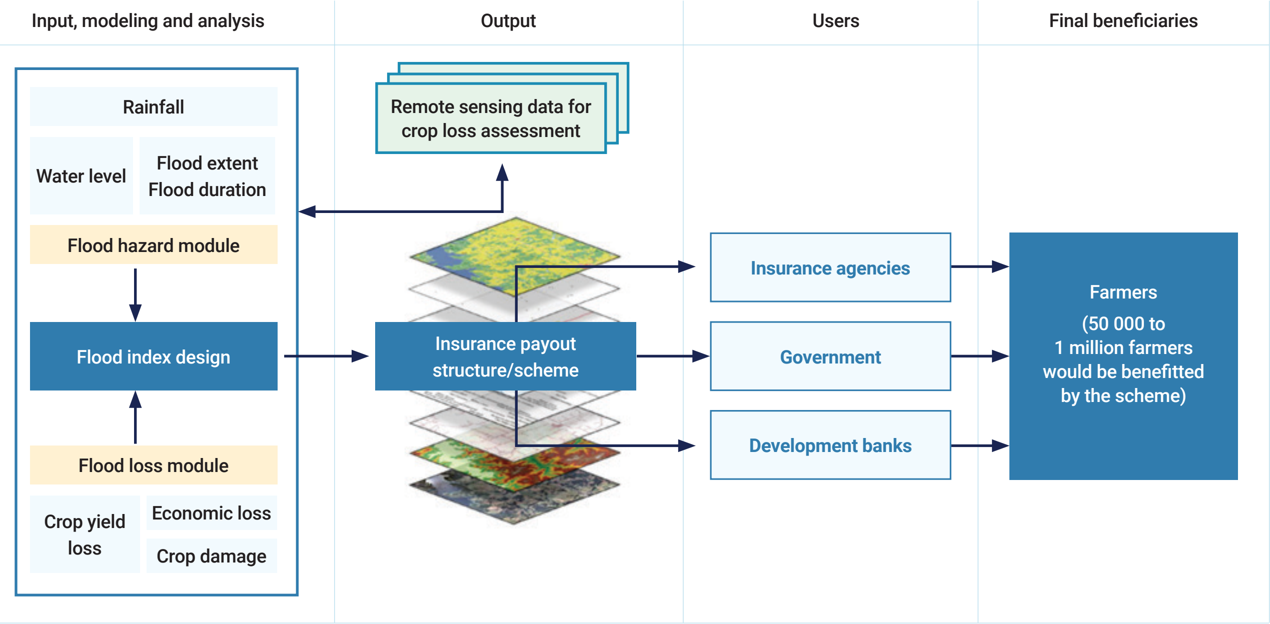
Drought and flood monitoring systems are an important component of risk reduction. However, they need to be embedded in a comprehensive drought/flood management strategy, which builds on an understanding of who and what is at risk and why, while identifying appropriate measures to reduce risk as well as ways to respond depending on a set threshold. Guidance for selecting measures has been developed in the flood management community (APFM, 2013a; 2013b).

Flood and drought insurance

Enhancing the accessibility to climate risk insurance enables communities to improve their resilience to disasters and plays an important role in supporting the recovery from extreme events, such as floods and droughts, by providing timely pay-outs. Insurance can support disaster preparedness and management if it is accompanied by requirements or incentives to take preventive measures, therefore constituting an important element of a cost-effective DRR strategy (UNDRR, 2017).

Insurance sets a minimum threshold for an acceptable level of risk by establishing a cost estimate on the risk and setting risk prevention standards. Resilience-building is incentivized as lower risks translate to lower premiums (GWP, 2018a). An index-based flood insurance scheme (Figure 4.5) can simplify decision-making and speeds the delivery of insurance pay-outs to compensate farmers for crops ruined by floods through a high-tech approach that has been demonstrated to be more efficient than conventional field assessments (Amarnath et al., 2017; Amarnath and Sikka, 2018).

Figure 4.5 Conceptual framework of an index-based flood insurance scheme, from design to implementation



Source: Amarnath (2017).

Furthermore, insurance companies can also mobilize significant finance for DRR through capital investments in resilience-building measures. Overall, insurance can help mobilize additional external finance because the economic risk from disasters is lower. Another possibility in the context of risk transfer mechanisms is the development of resilience bonds, which encourage investments in measures that build resilience (Hermann et al., 2016).

Urban planning

Urban planning is one of the soft/non-structural measures that provide excellent opportunities for DRR and CCA. For example, increased resilience to flood risks can be achieved by developing urban drainage systems that are integrated within urban infrastructure design to provide safe flooding spaces. The city thus acts as a 'sponge', limiting surges and releasing rainwater as a resource (Liu et al., 2016). The Delta Programme adopted by the Dutch Government to ensure the Netherlands is protected against flooding (van Herk et al., 2013; Gersonius et al., 2016) and the Tsurumi River Multipurpose Retarding Basin in Japan (Ikeuchi, 2012), which uses spaces normally used for parks and stadiums as floodwater retarding area, are two examples of successful integration of DRR in urban planning.

Contingency planning

Preparing a flood contingency plan to prepare for disasters increases the capacity of officers in charge of disaster response and enhances local resilience. One of the potential tools to achieve these objectives is 'evidence-based flood contingency planning', which is based on scientific approaches such as flood simulation and quantitative risk assessment. It consists of six steps: i) understanding of current conditions; ii) risk identification through a flood inundation simulation; iii) impact analysis; iv) development of a response strategy; v) development of a contingency plan; and vi) sharing the plan. This tool, which is designed to be applicable in any flood-prone area, has been tested in the Luzon Island in the Philippines (Ohara et al., 2018).

Marumori (Japan) after the typhoon Hagibis.

4.3 Planning and assessment methods for disaster risk reduction

To reduce water-related disaster risks under climate change, it is necessary to integrate DRR into different sectoral policies and plans (Birkmann and Von Teichman; 2010; Reinmar, et al., 2018). This mainstreaming process includes assessing the implications of disasters and climate change on any planned development action in all thematic areas and sectors at all levels. This also requires identifying existing sectoral policy and legal instruments, which already take DRR measures into account.

> *Mainstreaming gender and community involvement in decision-making processes should be a key element in DRR strategies*

Stakeholder involvement is crucial in all the steps in the development and implementation of DRR strategies. It is important to identify the stakeholders and their responsibilities in DRR, facilitate their involvement (different sectors, including local communities) by providing the relevant information to them, and build stakeholder capacity to make them more prepared for emergencies. Mainstreaming gender and community involvement in decision-making processes should be a key element in DRR strategies. The gender dimensions of DRR in the context of climate change is well expressed in *General Recommendation 37* of the Committee on the Elimination of Discrimination against Women (CEDAW, 2018).

A transboundary basin level DRR assessment provides opportunities to evaluate the most severe risks faced by the entire basin and to foster joint efforts among the riparian countries. Addressing disasters at the basin level extends the decision space and broadens the range of possible solutions (UNECE, 2009; 2015). Solutions to transboundary water-related disasters emanating from consultation and joint action between the riparian countries can help achieve mutual benefits (e.g. costs and data sharing, common early warning systems). It also makes preparedness more effective and help to avoid unilateral measures that may have negative impacts on other riparian countries. Approaches and tools for policy-makers and practitioners on how to address water-related disasters under climate change in transboundary basins are presented in UNECE/UNDRR (2018).

4.4 Opportunities

New knowledge and approaches to build resilient societies and to maximize the synergies between CCA and DRR are emerging (Birkmann and Von Teichman, 2010; Reinmar, et al., 2018) (see Chapter 13). Artificial intelligence (AI), 'big data', sophisticated climate and hydrological models, advanced remote-sensing technologies, NBS, and social media may all strengthen the global agendas in CCA and DRR. AI and machine learning have the potential to significantly improve efforts in environmental monitoring, flood forecasting and disaster communication (Sermet and Demir, 2018). Social media data streams can provide critical information for ungauged locations in flood monitoring (Wang et al., 2018b; Sit et al., 2019). Decision support systems (Demir et al., 2018; Newman et al., 2017) reinforced with serious gaming approaches can facilitate participatory decision-making in multi-hazard mitigation (Meera et al., 2016; Carson et al., 2018). Emerging techniques may not fully replace traditional DRR measures but may complement the latter to increase capacity to cope with water-related disasters (Gan et al., 2016).

Improved inter-agency coordination in water resources and disaster risk management is needed, especially in transboundary basins where it remains fragmented throughout most of the world

Maximizing the benefits of these innovative tools requires filling (or at least reducing) the gap between scientific knowledge and action taken by policy-makers and practitioners. Improved inter-agency coordination in water resources and disaster risk management is needed, especially in transboundary basins where it remains fragmented throughout most of the world. It is also important that these developments are linked to proactive policy and planning. Government agencies should not only anticipate events and know their extent and intensity when they occur. They should have developed and agreed action plans in place to react timely and properly to ensure that the costs of the impacts are managed, and that communities and businesses are able to return to normal as soon as possible.

5

Human health impacts related to water, sanitation and climate change

Jakun children learn how to wash their hands properly (Malaysia).

WHO | Kate Medlicott, Jennifer De France, Elena Villalobos-Prats and Bruce Gordon

With contributions from: Halshka Graczyk (ILO); Sarantuyaa Zandaryaa (UNESCO-IHP); Javier Mateo-Sagasta (IWMI); Rio Hada (OHCHR); Serena Caucci (UNU-FLORES); Vladimir Smakhtin (UNU-INWEH); and Lesley Pories (Water.org)

This chapter focuses on the human health impacts associated with changes in water quality and quantity due to climate change. Trends in morbidity and mortality are examined in the context of health risks associated with climate change, and response options related to water supply and sanitation are presented.

5.1 Introduction

It is becoming increasingly clear that climate change has severe impacts on health, and that many of these impacts are related to water. Climate change threatens all aspects of society, and the continuing delay in addressing the challenge further increases the risks to human lives and the right to health (WHO, 2018b). If current greenhouse gas (GHG) emission trends continue, climate change will trigger a range of health impacts concentrated on the poorest and most vulnerable populations, thereby deepening inequalities both within and between countries.

Climate change can be expected to cause an additional 250,000 deaths yearly by 2030 by hampering the progress that is being made against killers such as undernutrition, malaria and diarrhoea

Anticipated water-related health impacts of climate change are primarily food-, water- and vector-borne diseases, deaths and injury associated with extreme weather events such as coastal and inland flooding, as well as undernutrition as a result or food shortages caused by droughts and floods. Mental health impact associated with illness, injury, economic losses and displacement may also be substantial, although difficult to quantify. Even considering only a subset of the health risks, and making optimistic assumptions about economic growth, climate change can be expected to cause an additional 250,000 deaths yearly by 2030 by hampering the progress that is being made against killers such as undernutrition, malaria and diarrhoea (WHO, 2014).

The drivers of climate change (see Chapter 1) cause a heavy burden of disease (WHO, 2018b). Mitigation efforts focused on reducing GHG emissions will remain essential in maintaining the social and environmental conditions for combatting diseases in the long term. Such efforts are also needed to avoid uncertain, but potentially severe water-related risks that are determinants of health, including extreme weather events overwhelming health systems, breakdowns in food systems, large-scale population displacement and exacerbation of poverty. These factors threaten to reverse progress in health and overall development.

The impacts of climate change on health will likely lag behind GHG emission reductions by several decades, due to delays between changes in social and environmental determinants of health (e.g. migration due to food shortages) and the associated health outcomes (e.g. undernutrition and stunting, mental health consequences of migration). There is an important opportunity, however, for coordinated action to immediately address climate change and improve health by drawing on principles of the 'One Health' approach, which combines interventions with humans, animals and ecosystems to improve public health outcomes. Strengthening the resilience of water and sanitation services as well as health systems would save lives now and protect populations from much of the potential health impacts of climate change.

The international community has made important progress in recent years. Global climate and health agreements, most notably the Paris agreement (outcome document of the 21st Conference of the Parties (COP), or United Nations Climate Change Conference), now provide clear mandates for stronger action to protect human health from climate risks, and to promote the health benefits of cleaner development choices. A range of different policy and technical support options regarding water and, to a lesser extent, sanitation are currently available to support countries in their efforts to include health in adaptation and mitigation policies. What is needed now is a more systematic, evidence-based and scaled-up implementation (WHO, 2015b).

5.2 Trends in water-related morbidity and mortality

Realizing the human rights to access to safe and sufficient water and adequate sanitation, especially for the poorest, will enhance the health and quality of life of millions of people. So will improvements in personal, domestic and community hygiene. In addition, better management of water resources to reduce the transmission of vectorborne diseases, such as viral diseases carried by mosquitoes (Kibret et al., 2016), and to ensure that lakes and rivers used for recreation do not contain harmful levels of faecal pollution or algal blooms, can save many lives and has extensive direct and indirect economic benefits, at the households level as well as at the level of national economies (WHO, 2019a). Many foodborne illnesses (Table 5.1) are also related to poor quality of water used in food production, post-harvest processing and/or food preparation (WHO, 2006). Recent estimates suggest that the total area of cropland in peri-urban areas that is irrigated by mostly untreated urban wastewater has reached about 36 million hectares, equivalent to the size of Germany (Thebo et al., 2017).

Many foodborne illnesses are also related to poor quality of water used in food production, post-harvest processing and/or food preparation

Table 5.1 Health impacts of unsafe water and sanitation that can be exacerbated by climate change

Health Impact	Example
Human well-being	Lost time for economic or educational advancement and fear, anxiety and stress caused by distant and/or unsafe water and sanitation services, floods and droughts. Anxiety provoked by medical treatment costs in the case of illness and/or lost income while recovering from illness.
Microbial infections	Faecal-oral infections (diarrhoea, cholera, dysentery, typhoid, polio) and helminth infections due to a lack of sanitation and hygiene, contaminated water and food, or conditions caused by repeated microbial infections (stunting, pneumonia, anaemia). Vectorborne diseases due to poor water management.
Physical injury	Drowning and/or workplace injuries to water and sanitation workers. Physical injuries caused by floods.
Chemical poisoning	Ingestion of elevated levels of nitrates, fluoride, arsenic and other chemical pollutants in drinking water.
Undernutrition and stunting (and associated impaired cognition)	Repeated diarrhoea or helminth infections due to unsafe water and sanitation, causing environmental enteropathy, undernutrition and stunting. Insufficient food supplies due to a decrease in water availability for food production, causing undernutrition and stunting.
Issues of emerging concern	Antimicrobial resistance exacerbated by poor water and sanitation for infection prevention and control in communities and health facilities, and the discharge of antibiotic residues, resistant bacteria and genes in wastewaters further driving resistance.

Source: Based on WHO (2011; 2017; 2018b).

Inadequate water and sanitation have been conservatively estimated to cause nearly two million preventable deaths worldwide annually, as well as 123 million preventable Disability-Adjusted Life Years (DALYs),[8] with the greatest burden falling on children under five (WHO, 2019a) (Table 5.2). Since 2000, progress on mortality associated with all major water- and sanitation-related diseases has shown an encouraging downward trend (WHO, n.d.) commensurate with advances in access to improved water supply and sanitation. However, morbidity has been slower to decline and, in many regions, the social and economic burden of inadequate water, sanitation and hygiene (WASH) lies disproportionately on women and girls (e.g. lost opportunities for work or education due to water collection tasks or shame and anxiety about toilet use and menstrual hygiene management) (Wendland et al., 2017).

Table 5.2 Disease burden from inadequate WASH for the year 2016

Disease	Deaths	DALYs ('000)	Population attributable fraction
Diarrhoeal diseases	828 651	49 774	0.60
Soil-transmitted helminth infections	6 248	3 431	1
Acute respiratory infections	370 370	17 308	0.13
Malnutrition*	28 194	2 995	0.16
Trachoma	<10	244	1
Schistosomiasis	10 405	1 096	0.43
Lymphatic filariasis	<10	782	0.67
Subtotal drinking water, sanitation and hygiene	***1 243 869***	***75 630***	***NA***
Malaria	354 924	29 708	0.80
Dengue	38 315	2 936	0.95
Onchocerciasis	<10	96	0.10
Subtotal water resource management	***393 239***	***32 740***	***NA***
Drownings	233 890	14 723	0.73 (0.74 for LMIC, 0.54 for HIC)
Subtotal safety of water environments	***233 890***	***14 723***	***NA***
Total inadequate water, sanitation and hygiene	**1 870 998**	**123 093**	**NA**

Note: LMIC: low- and middle-income countries, HIC: high-income countries, DALYs: disability-adjusted life years, NA: not applicable. Disease burden estimates are for low- and middle-income countries. The estimates for diarrhoea, acute respiratory infections and drownings also include the disease burden in high-income countries.

* Includes disease burden from protein-energy malnutrition (PEM) and consequences in children under five only.

Source: WHO (2019a, table 2, p. 44).

At the end of the Millennium Development Goals period (2000–2015), 91% of the global population used an improved drinking water source and 68% used improved sanitation facilities (WHO/UNICEF, 2015). Much remains to be done to reach the new, higher levels of safely managed water supply and sanitation services, as defined under the Sustainable Development Goals (SDGs), for the 2.2 billion and 4.2 billion people, respectively, who lack this superior level of service (WHO/UNICEF, 2019). Safely managed services are essential to achieve significant health gains from WASH (WHO, 2014).[9]

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[8] Disability-adjusted life years (DALYs) is a measure of overall disease burden, expressed as the number of years lost due to ill health, disability or early death.

[9] Please consult the 2017 methodology updates of the Joint Monitoring Programme (WHO–UNICEF) and the SDG baselines for definitions of improved drinking water, improved sanitation, and safely managed water supply and sanitation services (WHO/UNICEF, 2018).

5.3 Health risks associated with climate change

The 2015 Paris agreement concluded that climate change is already affecting human health, with increasing exposure and vulnerability recorded worldwide. Furthermore, warming of even 1.5°C is not considered safe for human health. The physical and mental health of the most disadvantaged, vulnerable and poor populations is expected to be disproportionately affected. Thus, climate change is considered to be a poverty multiplier, which could force 100 million people into extreme poverty by 2030 (WHO, 2018b).

Climate change is considered to be a poverty multiplier, which could force 100 million people into extreme poverty

The direct health impacts of climate change include physiological effects from exposure to higher temperatures, increasing incidences of respiratory and cardiovascular disease and injuries, and death due to extreme weather events such as droughts, floods, heatwaves, storms and wildfires. Indirect effects on health arise from ecological changes, such as food and water insecurity and the spread of climate-sensitive infectious diseases, and also from societal responses to climate change, such as population displacement and reduced access to health services. Mental health impacts after extreme weather events, climate-related displacement, immigration and loss of culture can be lifelong. As indirect effects of climate change may result from long causal pathways, they are particularly difficult to anticipate or prevent (WHO, 2018b).

Water-related diseases affected by climate change via water are primarily food-, water- and vector-borne (with particular challenges in case of flooding), as well as deaths and injury associated with coastal and inland flooding and droughts. Health impacts can also occur due to increased exposure to pathogens, toxins or chemicals in drinking water, and undernutrition in the event that crops fail (WHO, 2017). Health impacts will disproportionately affect people working in occupations where they experience greater daily exposure to these hazards, including agricultural work (ILO, 2016).

Table 5.3 summarizes the main causal pathways by which exposures related to climate variability and change determine health impacts, primarily via drinking water quality and quantity. Climate-resilient Water Safety Plans (WSPs) have the potential to contribute to reduced disease rates by mitigating these effects.

A lot of uncertainty remains around the quantification of the additional burden of disease associated with climate change, due to the variability of climate scenarios and the mediating effect of societal responses (WHO, 2018b). However, it is clear that climate change is likely to slow or undermine progress on access to safely managed water and sanitation, and lead to ineffective use of resources if systems design and management are not climate-resilient. By extension, progress on the elimination and control of water- and sanitation-related disease will also be slowed or undermined by climate change. Past estimates of changes in disease due to climate change by 2030, compared to 2000 levels, point to a 10% higher risk of diarrhoea in some regions (McMichael et al., 2004). What's more, even relatively small losses of water and sanitation coverage at the community level due to poor climate resilience could have disproportionate effects on human health. For sanitation in particular, a small number of households with latrines that are periodically flooded, for example, may contaminate the whole community potentially exposing everyone in the community even if their own toilet was not affected. Therefore, ensuring climate-resilient water and sanitation services for entire communities will be critical to protecting public health (WHO 2018a; Wolf et al., 2019). In addition, climate change-related losses in rainfall and groundwater are likely to increase the demand for wastewater as an irrigation water source. Meanwhile, increased floods and droughts are likely to exacerbate water pollution by overflowing sanitation systems during floods, and concentrating pollution during droughts (HLPE, 2015). This will likely lead to more irrigation with lower quality of water, with commensurate increases in foodborne disease, unless sufficient treatment and on-farm and market control measures are in place (Qadir, 2018).

Climate change is likely to slow or undermine progress on access to safely managed water and sanitation

The capacity of disease vectors to spread infectious diseases is increasing as rising water temperatures will increase the range of favourable breeding sites for certain vectors for diseases (including malaria, dengue, West Nile and Lyme disease, as well as neglected tropical diseases). Insect and animal vectors may allow them to travel to areas such as Europe and North America, which were previously too cold to support transmission. For example, the vectoral capacity of the mosquitoes that are primarily responsible for the transmission of dengue fever has risen by approximately 10% since the 1950s (WHO, 2018b). This increase in range is also anticipated for malaria in regions bordering current endemic zones, with smaller changes occurring in currently endemic areas. Climate change and increases in population are also predicted to significantly exacerbate the impact of dams, which provide breeding sites for mosquitoes, on the spread of malaria, particularly in Sub-Saharan Africa (Kibret et al., 2016).

Ecological shifts due to climate-induced changes in water availability may cause food insecurity and undernutrition

Ecological shifts due to climate-induced changes in water availability may cause food insecurity and undernutrition. Climate variation and extremes are among the leading causes of severe food crises, and the cumulative effect is undermining all dimensions of food security, including availability, access, use and stability. Undernutrition is anticipated to be one of the greatest threats to health resulting from climate change. It is projected that 540–590 million people will be undernourished at a warming of 2°C, with the young and the elderly particularly affected. Rising temperatures, floods and droughts also affect food safety. For example, rising temperatures can increase the levels of pathogens in food sources (such as ciguatera in fish) and in food, while flooding increases the risk that pathogens will spread from livestock (WHO, 2018b).

The estimated proportional changes in the numbers of people killed or injured in storm surges and coastal floods are large and the acute health impacts (e.g. injury and drowning) of inland floods are predicted to increase by a similar proportion to those affected by undernutrition (WHO, 2018b). Increases in eutrophication and harmful algae blooms (HABs) caused by warmer water temperatures are of particular concern. Exposure to cyanotoxins from HABs through drinking water, fish and recreational activities cause acute or chronic poisoning in humans and animals (CRS, 2018). A recent study indicates cyanotoxin poisoning outbreaks have become more common over the past three decades (Trevino-Garrison et al., 2015).

When human health is compromised, other components of development are put at risk. For example, when an adult falls ill, they can neither work or care for others. If it happens to youth, they cannot attend school and parents may forego working to care for them. Meanwhile, medical bills are likely to accumulate, burdening household incomes. Households are therefore backsliding economically, and even facing economic migration (Chapter 8) as a consequence of dealing with the additional health burden of climate change. The failure to draw connections between water, sanitation and income is one of several oversights that led to development approaches that ignored financial markets as an important ally in the global effort to eradicate the water and sanitation crisis (Pories, 2016). The World Health Organization (WHO) estimates that universal access to safe water and sanitation would result in US$170 billion of economic benefits each year from reductions in healthcare costs and increased productivity from reduced illness (WHO, 2012).

5.4 Water supply and sanitation response options

In the face of climate change, meeting the health, nutrition and water targets of the SDGs will require sectoral but also coordinated and linked interventions (Ringler et al., 2018). Adaptation of water supply and sanitation services is critical to avert the potential health risks associated with climate change. In the case of sanitation, the choice of on-site sanitation facilities and wastewater treatment technologies and the way they are managed can also play a role in mitigation (WHO/DFID, 2009).

Adaptation measures to make water and sanitation systems more climate-resilient can be considered under six core components of health systems: policy and governance, financing, service delivery, technologies and infrastructure, workforce, and information systems (including monitoring, surveillance and research) (WHO, 2015c). Measures such as data collection and monitoring systems, disaster

Table 5.3 Health impacts of climate variability and change exposures: causal pathways

Water resources and drinking water supply		
Exposures affected by climate change	Potential impacts on water resources	Potential health and other impacts
Increased average temperatures	• Accelerated growth, survival, persistence, transmission and virulence of waterborne pathogens, compounded by reduced stability of chlorine residuals. • Increased formation of disinfection by-products. • Increased evapotranspiration and decreased water availability.	• Increased risks of foodborne and waterborne diseases from pathogens. • Possible increased risk of cancer with long-term exposure to disinfection by-products. • Impacts similar to those from droughts.
Increased drought	• Lower water availability for washing, cooking and hygiene, increasing exposure to waterborne contamination. • Increased concentration of pollutants when conditions are drier. This is of concern for groundwater sources that are already of low quality, for example in certain locations in India and Bangladesh, North and Latin America, and Africa, where concentrations of arsenic, iron, manganese and fluoride are often problematic. • Reduced groundwater tables and surface water flows may cause wells to dry up, increasing the distances to be travelled to collect (potentially unsafe) water, and increasing water source pollution. • Low rainfall may increase vector breeding sites by slowing river flows. • Decreased food security due to lower food production in the tropics; lower access to food due to reduced supply and higher prices. • Increased dam construction to adapt to more frequent droughts can intensify transmission and shift patterns of malaria infection (Kibret et al., 2015).	• Increased burden of foodborne and waterborne disease. • Fluoride: dental and skeletal fluorosis. • Arsenic: skin changes (pigmentation changes, hyperkeratosis), cancer (skin, bladder, lung), etc. • Iron and manganese: discoloured water, unpleasant taste. • Increased risk of health impacts associated with malnutrition resulting from the interaction of diminished food production and intake in poor regions, and higher rates of infectious disease. • Combined effects of undernutrition and infectious diseases; chronic effects of stunting and wasting in children.
More extreme precipitation events	• Lack of water for hygiene, flood damage to water and sanitation infrastructure, and contamination of water sources through overflow. • Heavier rainfall events and storm runoff, causing increased loading of pathogens, chemicals, and suspended sediment in surface waters. • Flooding causing overflow and contamination from sewerage systems, particularly where infrastructure is poor. • Long-term increases in rainfall cause rising groundwater levels, which may decrease the efficiency of natural purification processes. • Increased surface water may expand breeding sites for vectors while increased rain may favour vegetation growth and allow expansion in population of vertebrate hosts. • Flooding may also force vertebrate hosts into closer contact with humans. • Very high rainfall can reduce populations of insect vectors and intermediate hosts of infectious diseases (e.g. schistosomiasis) by flushing larvae from their habitat in pooled water.	• Increased risks of food- and waterborne diseases and of exposure to potentially toxic chemicals. • Increased or decreased risk of vectorborne diseases, depending on local ecology.

Water resources and drinking water supply (continued)		
Exposures affected by climate change	Potential impacts on water resources	Potential health and other impacts
Higher freshwater temperatures (with decreased concentration of oxygen and increased concentration of nutrients, such as phosphorus, and other factors)	• Shifting geographical and seasonal distributions of pathogens, e.g. *Vibrio cholerae* and *Schistosoma spp*. • Increased formation of harmful algae blooms (cyanobacterial and other bacteria) in freshwater. • More favourable conditions for microbial growth and proliferation associated with water-related pathogens. • Warmer, less oxygenated water can release increasing benthic nutrients (e.g. phosphorus), in turn promoting elevated phytoplankton activity, and release metals (e.g. iron and manganese) from lake sediments into the water body.	• Increased risks of foodborne, waterborne and water-based diseases such as cholera and schistosomiasis. • Liver damage, tumour promoter, neurotoxicity, dermatological and respiratory toxicity (longer-term effects depending on toxin exposed to). • Unpleasant taste and smell. • Impact on the productivity of water ecosystems with effects on food provision and security.
Sea level rise	• Coastal areas experiencing sea level rise may become uninhabitable and influence population displacement. • Sea level rise that increases the salinity of coastal aquifers, where groundwater recharge is also expected to decrease.	• Increased risk of waterborne diseases, health impacts of high salt consumption on non-communicable diseases.

Sanitation and wastewater management		
Climate change impact	Example impact on sanitation	Examples of associated health effects
More intense precipitation (leading to extreme rainfall events, floods, landslides, etc.)	• Flooding of on-site systems causing spillage, overflow and environmental contamination (e.g. in water supplies, floodwaters, surface water, soil).	• Increased risks of water- and vectorborne diseases and antimicrobial resistance spread. • Increased risks of health impacts associated with undernutrition.
Long-term declines in rainfall and runoff (leading to e.g. long-term drought, etc.)	• Declining water supply impeding function of water-reliant sanitation systems (e.g. flush toilets, sewerage).	• Increased risks of water- and vectorborne diseases (e.g. due to a lack of water for cleaning, resulting in poor sanitary conditions and poor hygiene). • Increased risks associated with undernutrition resulting from interaction with diminished food production and intake in poor regions, and increases in diseases associated with undernutrition. • Increased risk of water- and vector-borne diseases linked to untreated wastewater use for food production.
Higher temperatures (leading to e.g. warmer surface water and soil temperatures, heatwaves)	• Malfunction, breakdown or inaccessibility of sanitation systems deterring safe sanitation behaviours (e.g. strong odours during heatwaves deterring use of latrines).	• Health impacts resulting from unsafe use or non-use of sanitation systems (e.g. physical or mental conditions arising from suppressed urge to urinate/defecate).

Source: Based on WHO (2017; 2019b).

Table 5.4 Key adaptation and mitigation measures organized by health system building blocks

Category	Example
Policy and governance	National policies and strategies informed by WASH and health vulnerability assessments to ensure sustainability of investments (WHO, 2018a). Incorporation of the One Health approach, which addresses human, animal and ecological determinants of health.
Financing	Utilize risk management approaches to identify the cost of additional climate-related risks and to integrate these into water and health financing plans as well as water supply and sanitation infrastructure operating and financing plans (WHO, 2018a). Financial inclusion activities that provide low-income households with credit and/or insurance can enable victims of intense climate events to recover from house or crop destruction more easily.
Service delivery	Implementation of climate-informed water and sanitation risk management approaches at the local level, e.g. climate-resilient water safety planning (see WHO, 2017, table 3, p. 35 for examples of hazards and control measures) and climate-resilient sanitation safety planning (see WHO, 2016 and 2018b, table 3.6, p. 54 for sanitation system adaptation options), implemented by service providers and municipalities. Addressing water scarcity through safe use of wastewater in agriculture and groundwater recharge.
Technologies and infrastructure	Mitigation of emissions from sanitation and wastewater treatment, e.g. emissions from latrines and wastewater treatment plans (WWTP); potential for energy and biogas recovery. Strengthen the resilience of health, water and sanitation systems, e.g. climate-resilient WASH in healthcare facilities, readiness for climate-related admissions, and climate-resilient water and sanitation technologies (WHO, 2018a).
Workforce	Ensuring the adequate workforce for water and sanitation services and worker awareness. Training and protections in place to prevent workplace-related illness and injury from climate risks (ILO, 2016; WHO, 2018b).
Information systems (including monitoring and surveillance)	Ensuring health surveillance and monitoring systems include data on access and use of water and sanitation services and are analysed with climate data to inform adaption of health programmes and water and sanitation service delivery (WHO, 2018b). Strengthen monitoring and surveillance programmes for drinking, irrigation and recreational water, especially during extreme weather events and water-related disasters (WHO, 2018a).
Research	Identifying and addressing the key knowledge gaps in the interface of water, climate change and human health, including water quantity and quality modelling, to anticipate, change and plan climate-resilient services (Hofstra et al., 2019).

Source: Authors.

response and rehabilitation plans, and behaviour change programmes can support effective adaptation. Improved finance mechanisms for water and sanitation service providers that facilitate the ability of these entities to build emergency reserves would leave them better prepared to respond to climate events. Examples of key adaptation and mitigation measures are summarized in Table 5.4. Additional water sector adaption and mitigation measures are detailed in Chapter 3.

While many of the responsibilities for implementation of adaptation options lie outside health ministries, the health sector needs to fulfil its core functions within water supply and sanitation service delivery. One of these functions is to contribute to sector coordination and to ensure that health protections are included in norms and standards. Another primary function is to incorporate water- and sanitation-related climate risks into health policies, health surveillance systems and health promotion activities where water and sanitation are necessary for the primary prevention of illness and for reducing the use of antimicrobials.

Communal toilets in the Soweto township of Johannesburg, South Africa.

One aspect for which the health sector holds full responsibility is the climate resilience of healthcare facilities, including climate-resilient water supply and sanitation service within health facilities. The sector is also responsible for ensuring healthcare facilities' readiness to handle additional patient loads associated with extreme events, and to adapt to the slow changes in disease burden associated with climate change.

To plan and adopt the most cost-effective combination of solutions, it will be critical to develop models and scenario analysis frameworks that enable a better understanding of the sources of the local disease burden as well as the possible future changes as a result of climate change to inform climate-resilient and health-protective management of water resources (Hofstra et al., 2019).

6

Agriculture and food security

Communities terraced the hills and valleys during the dry season, so that they could retain topsoil, nutrients and water (Rwanda).

FAO | Marlos De Souza, Yo Nishimura and Jacob Burke

With contributions from: Christophe Cudennec (IAHS); Petra Schmitter, Amare Haileslassie and Mark Smith (IWMI); Stephan Hülsmann, Serena Caucci and Lulu Zhang (UNU-FLORES); and Bruce Stewart (WMO)

This chapter highlights where land–water linkages are expected to become apparent in terms of climate impacts and where practical approaches to land and water management offer scope for both climate adaptation and mitigation though agriculture. It also provides an agricultural perspective from which to further engage the United Nations Climate Change Conference in terms of water management.

6.1 Introduction

Climate is a resource for agriculture. Human systems of crop production, livestock husbandry, freshwater aquaculture and near-shore fisheries have adapted to distributions of temperature and precipitation over millennia. In this sense, agriculture's exposure to risks from day-to-day variations in weather and longer-term patterns of seasonal and interannual shifts in temperature and precipitation are well recognized, not least by farmers and commodity traders. It is the increasing rate and magnitude of these shifts and the prospects of further changes within the next 50–100 years that are cause for concern, particularly for the rural poor who have no alternative to agriculture for maintaining their livelihoods.

Despite the fact that the global food system has generally managed to meet growing demand for calories, 821 million people (or 11% of the global population) remain severely undernourished, and this number is rising in absolute terms. While the impact of abrupt weather-related shocks is generally acknowledged, chronic poverty, economic dislocation and market remoteness have made rural producers vulnerable to long-term climatic shifts. Drying trends, elevated night-time temperatures, frost incidence or increases in relative humidity will have long-term impacts on agro-ecological functions, in addition to short-term weather-related shocks. This disruption of food production patterns is not always substituted by alternative (imported) supply at affordable prices, and the systems of food aid distribution are not always able to satisfy demand for basic calories and nutritional supplements. It is therefore expected that increasing climate variability and weather extremes will threaten food security, including people's access to healthy and nutritious diets (FAO/IFAD/UNICEF/WFP/WHO, 2018).

Under climate change, the specific challenges for agricultural water management are twofold. First, there is the challenge to adapt existing modes of production to deal with higher incidence of water scarcity (physical and economic) and water excess (flood protection and drainage). Second, the challenge to respond to the policy drives to 'decarbonize' agriculture through climate mitigation measures that reduce greenhouse gas (GHG) emissions and enhance water availability. The role of agricultural water management is central to agriculture's adaptive response, allowing flexible crop production cycles in cash crops and some staple foods, notably rice. Soil moisture management in rainfed soils is also crucial in maintaining soil structure and promoting root growth and plant establishment to sequester carbon.

The global scale of these challenges is not trivial. Agriculture, forestry and other land use, termed the AFOLU 'sector' by the Intergovernmental Panel on Climate Change (IPCC), is estimated to account for 23% of total anthropogenic GHG emissions for the period 2007–2016 (IPCC, 2019b). Reported agricultural statistics (FAOSTAT, n.d.) indicate that by 2016, 37% (48.7 million km²) of the total land area (130.1 million km²) was under some form of agricultural management. This includes cultivated land, permanent crops, pasture and managed wetlands. The rate at which land use conversion is occurring and the trend in higher-intensity agricultural inputs on land (inorganic fertilizer in particular) set a high bar for the adoption of sustainable adaptation measures and effective mitigation measures, which are crucial if the sector is to make a positive contribution to reaching climate targets.

The detrimental environmental outcomes from the current food production system have been raised, particularly with respect to emissions, biodiversity loss and natural resource depletion, as part of the so-called 'planetary boundaries' (Springmann et al., 2018; Willet et al., 2019). Given these established land and water limits, global initiatives in the sustainable intensification of agriculture, maintaining levels of growth in agricultural production while reducing the growth in inputs and emission levels, are already in evidence under the umbrella term 'Climate-Smart Agriculture' (CSA) (Box 6.1).

There are still 2.1 billion poor people and 767 million people living in extreme poverty, 80% of whom live in rural areas

CSA is a recognized suite of well-informed approaches to land and water management, soil conservation and agronomic practice that anticipate climatic variability, can sequester carbon and reduce GHG emissions. In many cases, these are well established conservation agriculture practices (Corsi, 2019) that can be packaged to retain soil structure, organic matter and moisture under drier conditions, but they also include agronomic techniques (including irrigation and drainage) to adjust or extend cropping calendars to adapt to seasonal and interannual climate shifts. The flexibility offered by irrigation and drainage makes water management an attractive adaptive response with excellent carbon sequestration for both temporary and permanent crops. However, this flexibility can come at a cost in terms of local water resource depletion and water quality deterioration. Nature-based solutions (NBS) to water scarcity and water quality deterioration also have to be taken into account. These include landscape restoration as part of agricultural practice (WWAP/UN-Water, 2018).

There are still 2.1 billion poor people and 767 million people living in extreme poverty, 80% of whom live in rural areas, with the global distribution of poverty highly skewed (95% of rural poor) toward Sub-Saharan Africa and South/Southeast Asia (World Bank, 2016b). The Food and Agriculture Organization of the United Nations (FAO) estimates that some 475 million smallholder farms (up to 2 hectares in size) produce subsistence and cash crops on only 12% of global farmland (FAO, 2015b).

Climate change is expected to increase the incidence of rural poverty. Even small shifts in seasonality can prompt food insecurity (as food prices rise) and also result in increased incidences of plant, animal and human disease. The aggregation of such weather-related shocks can then progressively lower rural incomes and economic growth, severely compromising the rural poor's access to land, water, forest and fish resources. With the overall reduction of their primary asset base, the long-term resilience of the rural poor decreases (FAO, 2019).

The combined impacts of changes in temperature and incidence of extreme weather in tropical zones are expected to push these already vulnerable populations further into extreme poverty or out of agriculture altogether. As such, climate change is recognized as an obstacle to ending rural poverty. With 80% of the impacts of drought absorbed by rural producers, the pressure on local water resources and reliance on water-lifting technology in particular is expected to increase (FAO, 2019).

It is therefore significant that climate–land interactions and the role of agricultural management in generating or offsetting GHG emissions are the subject of an IPCC Special Report on climate change and land (IPCC, 2019b). It is also significant that agricultural water management is now an explicit part of the climate negotiations, given the commitments made under the Decision 4/CP.23 Koronivia Joint Work on Agriculture (UNFCCC, 2017) (Box 6.2).

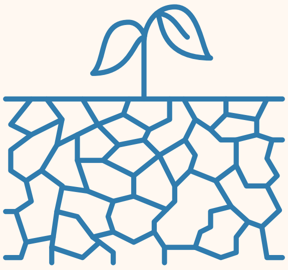
6.2 Climate impacts and the agriculture baseline: sorting out shocks from trends

The immediate effect of global warming in accelerating the hydrological cycle and raising the evaporative power of the atmosphere is expected to result in increased demand for water resources, as the agriculture sector strives to keep pace with growth in demand for production (FAO, 2011b). The range of climate impacts on agriculture and the implications for agricultural water management have been set out in a comprehensive typology indicating the relative vulnerability and adaptability across the major agricultural systems (Table 6.1), including the risk-sensitive areas highlighted in the Prologue. Water management response options indicate the range of adaptive approaches applicable to each case.

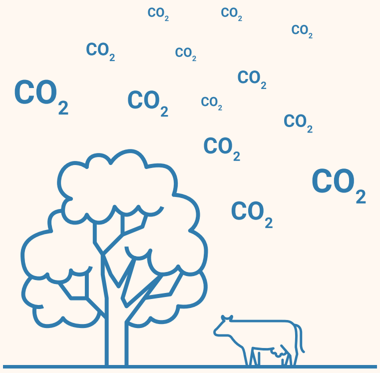
Box 6.1 Climate-Smart Agriculture

Sustainably increase agricultural productivity and incomes

Adapt and build resilience to climate change



Reduce and/or remove greenhouse gas emissions where possible



Source: Based on FAO (2017b).

"Climate-Smart Agriculture (CSA) is an approach for developing actions needed to transform and reorient agricultural systems to effectively support development and ensure food security under climate change. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible." (FAO, n.d.a).

"CSA is not a set of practices that can be universally applied, but rather an approach that involves different elements embedded on-farm and beyond the farm and incorporates technologies, policies, institutions and investment." (FAO, 2017b).

Selected adaptation measures include:

- Alternate wetting and drying of irrigated rice;
- Intercropping to reduce canopy temperatures;
- Climate-smart pest management;
- Index-based risk management tools.

Selected mitigation measures to reduce greenhouse gas (GHG) emissions include:

- Solar-powered pumping to reduce petroleum-based energy inputs and related emissions;
- Site-specific nutrient management to reduce inorganic fertilizer input and increase soil organic matter (carbon) retention.

Measures with co-benefits include:

- Conservation agriculture* techniques to increase soil carbon sequestration, retain soil moisture and avoid soil disturbance;
- Soil fertility management to reduce GHG emissions from inorganic fertilizers, to improve water-holding capacity.

Additional information about CSA can be found online, in:

- Sourcebooks and e-learning courses;[1]
- Related compendiums.[2]

"Conservation agriculture is a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance (i.e. no tillage, seed drilling) and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, thereby contributing to increased water and nutrient use efficiency and to improved and sustained crop production" (FAO, n.d.b).

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[1] For further information, please see www.fao.org/climate-smart-agriculture-sourcebook/en.

[2] For further information, please see www.fao.org/gacsa/resources/gacsa-csa-documents/en/.

Table 6.1 Typology of climate impacts on water management in major agricultural systems

System	Current status	Climate change drivers	Vulnerability	Adaptability	Response option
1 Snow melt system					
Indus	Highly developed, water scarcity emerging. Sediment and salinity constraints.	20 years of increasing flows followed by substantial reductions in surface water and groundwater recharge. Changed seasonality of runoff and peak flows. Increased peak flows and flooding. Increased salinity. Declining productivity in places.	Very high (run of river): medium high (dams).	Limited room for manoeuvre (all infrastructure already built).	Water supply management: increased water storage and drainage; improved reservoir operation; change in crop and land use; improved soil management; water demand management, including groundwater management and salinity control.
Ganges Brahamaputra	High potential for groundwater use, established water quality problems. Low productivity.		High (falling groundwater tables).	Medium (still possibilities for groundwater development).	
Northern China	Extreme water scarcity and high productivity.		High (global implications, high food demand with great influence on prices).	Medium (adaptability is increasing due to increasing wealth).	
Red and Mekong Rivers	High productivity, high flood risk, low water quality.		Medium.	Medium.	
Colorado River	Water scarcity, salinity.		Low.	Medium (excessive pressure on resources).	
2 Deltas					
Ganges Brahamaputra	Densely populated. Shallow groundwater, extensively used. Flood adaptation possible; low productivity.	Rising sea level. Storm surges and infrastructure damage. Higher frequency of cyclones (East/Southeast Asia); saline intrusion in groundwater and rivers; increased flood frequency. Potential increase in groundwater recharge.	Very high (flood, cyclones).	Poor, except salinity.	Minimize infrastructure development; conjunctive use of surface water and groundwater; manage coastal areas.
Nile River	Delta highly dependent on runoff and Aswan storage – possibility for upstream development.		High (population pressure).	Medium.	
Yellow River	Severe water scarcity.		High.	Low.	
Red River	Currently adapted but expensive pumped irrigation and drainage.		Medium.	High, except salinity.	
Mekong River	Adapted groundwater use in delta – sensitive to upstream development.		High.	Medium.	

System	Current status	Climate change drivers	Vulnerability	Adaptability	Response option
3 Semi-arid/arid tropics: limited snowmelt/limited groundwater					
Monsoonal: Indian subcontinent	Low productivity. Overdeveloped basin (surface water and groundwater).	Increased rainfall. Increased rainfall variability. Increased drought and flooding. Higher temperatures.	High.	Low (surface irrigation); medium (groundwater irrigation).	Storage dilemma; increased groundwater recharge and use; higher-value agriculture (Australia).
Non-monsoonal: Sub-Saharan Africa	Poor soils; flashy systems; over-allocation of water, population pressure in places. Widespread food insecurity.	Increased rainfall variability. Increased frequency of droughts and flooding. Lower rainfall, higher temperature. Decreasing runoff.	Very high. Declining yields in rainfed systems. Increased volatility of production.	Low.	
Non-monsoonal: Southern and Western Australia	Flashy systems; over-allocation of water; competition from other sectors.		High.	Low.	
4 Humid tropics					
Rice: Southeast Asia	Surface irrigation. High productivity but stagnating.	Increased rainfall. Marginally increased temperatures. Increased rainfall variability and occurrence of drought and floods.	High.	Medium.	Increased storage for second and third season; drought and flood insurances; crop diversification.
Rice: southern China	Conjunctive use of surface water and groundwater. Low output compared to northern China.		High.	Medium.	
Rice: Northern Australia	Fragile ecology.		Low.	High.	
Non-rice: surface or groundwater irrigation			Medium.	Medium.	
5 Temperate areas					
Northern Europe	High-value agriculture and pasture.	Increased rainfall; longer growing seasons; increased productivity.	Surface irrigation: medium; groundwater irrigation: low.	Surface irrigation: low; groundwater irrigation: high.	Potential for new development. Storage development; drainage.
North America	Cereal cropping; groundwater irrigation.	Reduced runoff, increased water stress.	Medium.	Medium.	Increased productivity and outputs; limited options for storage.
6 Mediterranean					
Southern Europe	High water scarcity.	Significantly lower rainfall and higher temperatures, increased water stress, decreased runoff.	Medium.	Low.	Localized irrigation, transfer to other sectors.
Northern Africa	High water scarcity.		High.	Low.	Localized irrigation, supplementary irrigation.
7 Small islands					
Small islands	Fragile ecosystems; groundwater depletion.	Seawater rise; saltwater intrusion; increased frequency of cyclones and hurricanes.	High.	Variable.	Groundwater depletion control; water demand management.

Source: FAO (2011b, table 4.2, pp. 73–74).

Box 6.2 Making agricultural water use visible in the United Nations Climate Change Conferencing process

At the 23rd Conference of the Parties (United Nations Climate Change Conference 2017, COP23), Parties reached a decision on next steps for agriculture within the United Nations Framework Convention on Climate Change (UNFCCC). Known as the Koronivia Joint Work on Agriculture (KJWA), this landmark decision represents an important step forward in the negotiations within the UNFCCC related to agriculture and food security.

Parties and stakeholders are invited to work together under this decision to make sure that agricultural development ensures both increased food security in the face of climate change and a reduction in emissions. The KJWA will address six topics across the agricultural sectors related to food security and socio-economic impacts of climate change on soil, livestock, nutrients and water management.

Work under the KJWA will bring water into the negotiations process of the UNFCCC for the first time, since 'water management' in agriculture cannot be done in isolation of other sectors. Therefore, an integrated water resources management approach will be applied, meaning that 'other non-agricultural water uses' will also be reflected in the discussions.

In general, the impacts of changing temperature distributions can be anticipated and long-term adaptation approaches adopted on the basis of climate model projections. However, the increased volatility of precipitation, and rainfall in particular (intensity, duration and frequency), challenges adaptive responses in some of the most productive agricultural systems. It also impedes attempts to incorporate atmospheric moisture in General Circulation Models (GCMs). The range of modelled water stress attributed to agricultural water withdrawals in the IPCC Special Report on land is illustrative of the uncertainty associated with the various model projections that have been assessed (IPCC, 2019b). Nonetheless, global warming, combined with increased climatic variability and an accelerated hydrological cycle, will offer new agro-climatic opportunities (e.g. extended growing seasons) for some, while creating impediments for others (e.g. prolonged or shifted periods of soil moisture deficit). These shifting patterns of production are occurring in an economic context that is constrained by narrowing natural resource options and intersectoral competition for land and water. The structural transformation of agriculture in general (working populations coming out of agriculture plus uptake of new technology) will also influence the types and processes of adaptation and the opportunities for GHG mitigation.

The global production of food, fibre and industrial crops continues to grow broadly in line with demand. Medium-term projections to 2027 for agricultural production and consumption suggest a general deceleration of growth as demand progressively diminishes (OECD/FAO, 2018). Longer-term projections to 2050 (FAO, 2017a) point to higher rates of growth in demand for calories in low- and middle-income countries, together with heightened production risks resulting from incremental changes in climatic regimes and associated extreme events, particularly in the Middle East (FAO, 2017a). The anticipated impact of climate change on all aspects of agricultural production are recognized in these macro-economic projections. IPCC (2014a) and Ray et al. (2015) conclude that up to a third of global crop yield variability can be explained by climate variation, but it has not proved possible to quantify those impacts comprehensively through climate modelling. Changes in agricultural water demand also remain difficult to project. For instance, the 2019 IPCC Assessment on climate and land points to a very wide range in modelled projections for irrigation water demand, from a current baseline of around 2,500 km^3/yr in 2005 to between 2,900 and 9,000 km^3/yr by 2100 (IPCC, 2019b).

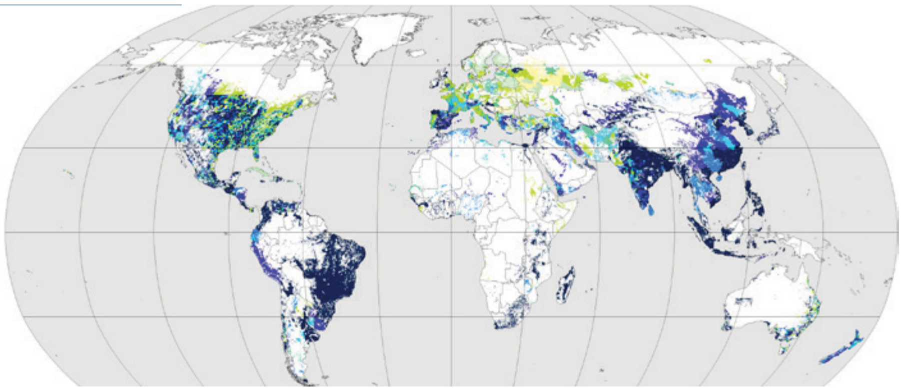
Anticipated climate forcing of large agri-food systems under Representative Concentration Pathway (RCP) scenarios has been examined in the IPCC *Fifth Assessment Report* (IPCC, 2014a). It suggests that some shifts between rainfed and irrigated production will be required to accommodate the aggregate impact of water limitations and CO_2 enrichment (Elliot et al., 2014). Further, changes in regional precipitation patterns impacting agricultural production have been projected to emerge by 2040 for four major crops: wheat, soya, rice and maize (Rojas et al., 2019). This points to some urgency in the adoption of adaptation measures with mitigation co-benefits in order to maintain levels of agricultural production.

6.2.1 Agricultural water demand

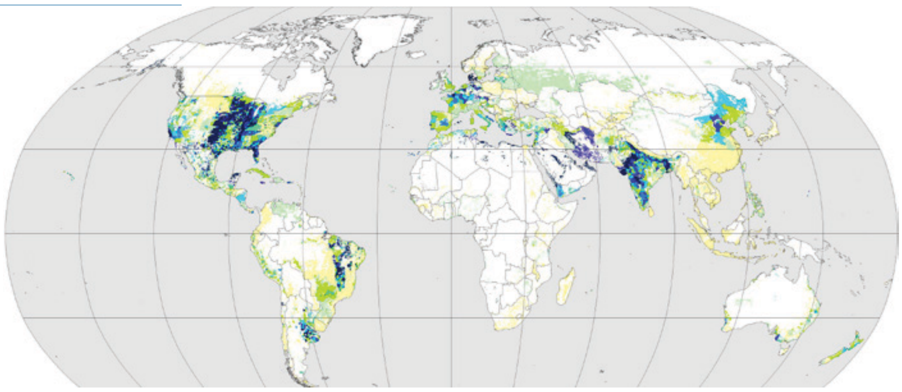
Irrigation land, which is responsible for 69% of global water withdrawals (AQUASTAT, 2014), is where the impact of elevated temperatures and aridity will be felt most. Although the current extent of this type of land (about 3,3 million km^2) accounts for only 2.5% of the total land area (Figure 6.1), it does represent 20% of cultivated land and generates some 40% of the global agricultural output (FAOSTAT, n.d.). It is also where the process of water withdrawal, diversion, application and drainage can produce a set of long-term environmental externalities, notably aquifer depletion, soil salinization and pollution from runoff and drainage. Statistical estimates of the area serviced by groundwater are in the order of 1,250,000 km^2 (Siebert et al., 2013), most of which is powered by non-renewable energy. This is in addition to the proliferation of energized pumping for distribution and drainage on surface irrigation schemes.

Figure 6.1 Percentage of area equipped for irrigation

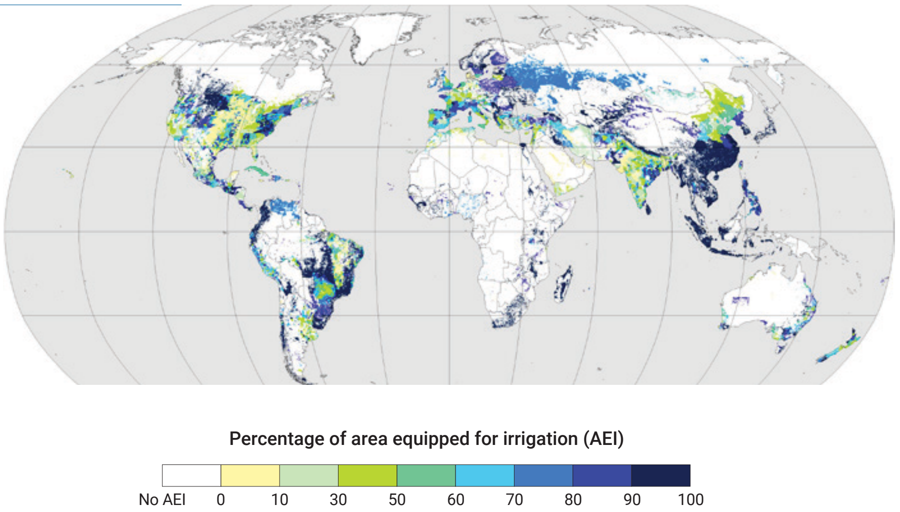
a) **Area actually irrigated**



b) **Area irrigated with groundwater**



c) **Area irrigated with surface water**



Source: FAO-AQUASTAT/Universität Bonn (2013).

The use of water by agriculture dominates global water use, but competition from other sectors is slowing the growth of freshwater allocations to the agriculture sector. The global baseline from aggregate reported statistics for the year 2010 estimated agricultural withdrawals at 2,769 km^3/yr, up from an estimated 2,300 km^3/yr in 1990 (AQUASTAT, 2014) (see Figure 15).

Expansion and intensification of crop production on irrigated land is the most significant driver of agricultural water demand, while locally, agro-forestry and water storage for livestock and aquaculture have also impacted basin and catchment water accounts. The *Comprehensive Assessment of Water Management in Agriculture* (2007) and the report *Managing Systems at Risk* (FAO, 2011a) pointed to mounting evidence of river basin closure and breakdown of large-scale agricultural systems, such as irrigated deltas and alluvial plains dependent upon groundwater. In the case of irrigated production, incremental evaporation over and above natural rates has been calculated by Hoogeveen et al. (2015) at 1,268 km^3/yr, which indicates global irrigation application efficiencies of around 50% when set against water withdrawals of 2,769 km^3/yr. This difference between withdrawals from surface and groundwater and the volumes consumed through beneficial evaporation (transpiration, cooling and weed suppression) is either recycled through return flows or aquifer recharge, or lost to non-beneficial evaporation from canals and off-line storage or the drained margins of irrigation schemes. While the management of rainfed land (including pasture) has generally neutral effects on evaporation processes, the impact on runoff and direct recharge processes can be significant if soil structure is lost through tillage and compaction, losing infiltration and soil moisture-holding capacity.

Annual growth rates of areas equipped for irrigation have been slowing, as indicated by agricultural statistics up to 2016 (Seibert et al., 2015; FAO, 2017a). Still, the growth is positive and within this expanding area, the intensification of water consumption is apparent as cropping intensities increase and irrigation technology, including pressurized drip and sprinkler methods, are adopted where they suit field crops and cropping conditions. However, assumptions that the adoption of irrigation technology will result in reduced water withdrawals appear to be ill-founded. Evidence from national initiatives intended to 'save' water through the introduction of pressurized irrigation suggests that the effect is quite the reverse and that adoption of irrigation technology tends to expand irrigated areas and increase the rate of water consumption (Perry et al., 2009; Lopez-Gunn et al., 2012; Scott et al., 2014; Molle and Tanouti, 2017; Grafton and Wheeler, 2018). This growth in agricultural water withdrawals in relation to advanced irrigation technologies has been apparent in river basin water accounts and particularly in the depletion of both confined and unconfined aquifer storage (Molle and Wester, 2009).

The role of groundwater in agriculture and rural development is often underestimated (IAH, 2019) and economic competition for high-quality groundwater from other sectors, notably industry and municipal supplies, is impacting adjacent rural areas (Flörke et al., 2018), where millions of smallholders rely on access to shallow groundwater circulation to buffer for dry-season recessions and extended periods of drought. The extent of shallow and deep groundwater extraction structures, together with small dam structures for irrigation, aquaculture and stock watering purposes, is not systematically recorded at subnational levels, making the estimate of areas equipped for irrigation and water withdrawals from areas that are actually irrigated subject to a degree of uncertainty (Siebert, et al., 2015).

> *The role of groundwater in agriculture and rural development is often underestimated*

The water footprint of livestock is not just limited to the consumptive evapotranspiration on grazing land, but now involves extensive systems of water supply for watering and cooling of live animals as well as irrigation water for production of fodder and imported protein concentrate (notably soya) or grain (poultry feed) (Mekonnen and Hoekstra, 2012; Ray et al., 2015). The growth projections in meat production to 2030 are remarkable – a 77% increase in beef, pork, poultry and sheep is projected for developing countries and a 23% increase from 2015–2017 levels for developed countries (FAO, 2017a). Non-ruminants (pigs and poultry) are expected to see the highest growth rates. Given this expected growth, the extent of grazing land and its sensitivity to drought are important, since feed substitutes (soya and cereals) are predominantly rainfed and are likely to be impacted, unless production is buffered by irrigation. The feedlot model of zero grazing with irrigated legumes and grasses is employed both in in the Middle East and the United States of America (USA), but also gaining broader hold in semi-arid and temperate climates where pasture would otherwise be damaged under dry and waterlogged conditions. As consumption of animal protein and dairy products drives a growing livestock population (Gerber et al., 2013; FAO, 2017a), the production of feed/forage/crop residues (in both rainfed and irrigated systems) plus direct consumption of surface and groundwater for livestock watering and cooling is resulting in a continued growth of water withdrawals by the animal husbandry sector.

Production of inland capture fisheries is reported at nearly 12 million tonnes (FAO, 2018c) with the majority of production coming from Africa, Asia and China (FAO, 2018d) as a mix of lake, river, wetland and aquaculture sources. Inland fisheries can benefit from nutrient enrichment derived from agricultural runoff, but they are also extremely sensitive to eutrophication, pollution, habitat degradation and interruption of water flows (FAO, 2018d). Inland capture fisheries as well as freshwater aquaculture systems (including rice-fish systems) are increasingly stressed by pollution loads and the hydraulic management of inland waterways and water bodies, including dams and reservoirs that are created for irrigation systems, hydropower engines, as well as agricultural water demands and runoff. In all, combinations of reduced flow, higher concentrations of pollutants and higher temperatures have significant impacts on fish mortality (FAO, 2018d). This is a concern since freshwater ecosystems have relatively low buffering capacity compared with marine ecosystems, and are therefore comparatively sensitive to climate-related shocks (FAO, 2018d).

Biofuel production (ethanol and biodiesel) is estimated to have only a small (1.7%) impact on agricultural water withdrawals (De Fraiture et al., 2008) since most sugarcane feedstock is rainfed. Growth projections are also modest (OECD/FAO, 2019), given the effect of current blending mandates in the main producing countries and the depressed crude oil prices globally. The irrigation of biofuels (notably from sugarcane and sugar beet) need careful water and energy accounting to establish net technical benefits in offsetting fossil fuel consumption and related emissions (see Box 9.1).

As agricultural productivity has increased (relative to both land and water), crop selection and cropping calendars have become finely tuned to relatively stable meteorological conditions. Where high-value crop production is limited by temperature and aridity, precision production is taken ‘indoors’ to minimize the effect of climatic variability. Such irrigated areas under shade netting, plastic mulch and greenhouses are expanding, and the proliferation in the Mediterranean and North China is such that disposal of plastic and plastic waste residue in soils is now producing a large environmental externality (Gao et al., 2019). Adaptation to higher temperatures is also influencing all forms of livestock production, with intensive production being taken ‘indoors’ and driving demand for irrigated fodder and feed cereals, while concentrating point demand for energy and water supply as well as point sources of pollution from animal waste (Gerber et al., 2013).

6.3 The role of agricultural water management in adaptation

6.3.1 Scope for adaptation

Under the umbrella of CSA, a range of adaptive approaches and technologies are being promoted to maintain levels of agricultural production as warming occurs and precipitation patterns change (Box 6.1).

The scope for adaptation in rainfed agriculture is determined largely by the ability of crop varieties to cope with shifts in temperature and to manage soil water deficits. Conditioning of soils to optimize soil moisture retention may include many conservation-agricultural techniques, including no-tillage and surface mulching with crop residues, thereby temporarily raising soil organic carbon. Where root crops are grown in temperate latitudes, the uptake of plastic mulching has become commonplace to protect early crops from frost and retain soil moisture by inhibiting evaporative loss to the atmosphere. Plant breeding (for drought tolerance, lodging inhibition), cropping calendar (phenological) adjustments, nutrient targeting and specific plant protection/integrated pest management are additional elements of CSA that can be applied. Certainly, for rainfed agriculture, the climate risks remain. No matter how much land and soil preparation is undertaken, if rainfall is inadequate to maintain acceptable soil moisture deficits across the growing season, crops will fail and the chances of the initiative being repeated will be small. This points to the importance of communicating seasonal and daily forecasts to the smallholders who are making the direct investment in land preparation, improved seed varieties and fertilizer.

Irrigation allows cropping calendars to be rescheduled and intensified, thus providing a key adaptation mechanism for land that previously relied solely on precipitation (i.e. rainfed) (Box 6.3). Adaptation here may simply be the acceleration of planned performance enhancements (modernization of both hardware and software) to improve the efficiency of water delivery and drainage services. These are the no-regrets options detailed in the irrigation and drainage literature (e.g. FAO, 2011b; De Vries et al., 2017), which can include building in system redundancy to protect against flood damage and enhance recharge and return flows. In-field adaptation to higher temperatures and evaporation is limited to either net shading or the introduction of planted shade (including intercropping or agroforestry).

6.3.2 Practical agricultural water management responses that can be taken to scale

The water-related elements of CSA have been elaborated into a set of land and water management techniques that conserve soil moisture content over the growing season and can be implemented at local scale as a package of climate-informed measures (Figure 6.2) (Aggarwal et al., 2018). Precision irrigation under many forms of climate control (shade netting, plastic mulching and greenhouses) and the deliberate use of deficit irrigation to improve the quality of horticultural products are widely practiced. Uptake of solar power to substitute diesel or petrol-based pumping is now occurring at scale, particularly when incentivized through subsidies (Shah et al., 2018). Many locally applicable agronomic practices that have been standardized for the prevailing climate can simply ‘tweaked’ or rescheduled as a reaction to higher quality and frequency of agrometeorological information.

Figure 6.2 Climate-Smart Agriculture water responses at local level

Weather-smart	Water-smart	Seed/breed-smart	Carbon/nutrient-smart	Institutional/market-smart
Weather forecasts	Aquifer recharge	Adapted varieties	Agroforestry	Cross-sector linkages
Agro-advisories	Rainwater harvesting	Adapted breeds	Minimum tillage	Local institutions
Weather insurance	Community management of water	Seed bank	Land use system	Gender strategies
Climate analogues	Laser levelling		Livestock management	Contingency planning
Avoided maladaptation	On-farm water management		Integrated nutrient management	Financial services
	Solar pumps		Biofuels	Market information
				Off-farm risk management

Source: Adapted from Aggarwal et al. (2018, fig. 3). Licensed under CC BY-NC 4.0. Photos: Weather-smart: © FAO/Marco Palombi; water-smart: © FAO/A. Brack; seed/breed-smart: © FAO/Sia Kambou; carbon/nutrient-smart: © FAO/Eduardo Soteras; and institutional/market-smart: © FAO/Daniel Hayduk.

What are the shifts in approach that can sharpen these adaptive responses? One key area where water resource management and agrometeorology can progress is through the development of operational information products that can be disseminated at scale and linked to field-level monitoring by farmers themselves. These include the following:

- Seasonal climate forecasts for upcoming months and even years are now widely available (WMO, 2016). Timely, actionable and reliable climate forecasts can play a crucial role in both short-term and long-term decision-making for farmers. The choice of planting dates and seasonal cropping calendars for high-yielding crop varieties offers a level of precision adjustment in planning the most weather-dependent economic sector (CIE, 2014).

Box 6.3 Potential of deficit and supplemental irrigation under climate variability in a semi-arid area: a savannah region in Togo

In the context of a growing population in West Africa and frequent yield losses due to erratic rainfall, it is necessary to improve stability and productivity of agricultural production systems, for instance by introducing and assessing the potential of alternative irrigation strategies that may be applicable in this region. For this purpose, a set of irrigation management strategies, ranging from no irrigation (NI) to controlled deficit irrigation (CDI) and full irrigation (FI), were evaluated in a dry savannah of Togo. The results show high variability in rainfall during the wet season, which leads to considerable variability in the expected yield for rainfed conditions (NI). This variability was significantly reduced when supplementary irrigation was introduced to top up rainfall shortfalls at critical points in the plant development, requiring a reasonably low water demand of about 150 mm. For the dry season, it was shown that both irrigation management strategies (CDI and FI) increased yield potential for the local maize varieties with up to 4.84 tonnes/ha and decreased the variability of the expected yield at the same time. However, even with CDI management, more than 400 mm of water would be required to introduce irrigation during the dry season in northern Togo. Substantial rainwater harvesting and irrigation infrastructure would thus be needed to introduce full irrigation in the dry season, which points to the input cost risk in trying to bridge rainfall shortfalls.

Source: Extracted from Gadédjisso-Tossou et al. (2018).

- Near-real-time weather information is now becoming readily accessible, allowing farmers to make decisions over crop protection (damaging rainfall, frost, disease) and crop insurance cover. These types of services are being extended where mobile telephone networks extend into rural areas (Asia and Southeast Asia particularly).

- At field level, in-situ soil moisture monitoring technology is advancing with the deployment of low-cost electromagnetic sensors and in combination with high-resolution remote sensing techniques (Manfreda et al., 2018). While current technology may be only applicable to high-value precision agriculture or research projects, the deployment of real-time soil moisture monitoring to schedule irrigation is expected to come down in cost.

- The integration of operational water accounting into CSA has already helped local agriculture water budgeting to be linked to basin-level hydrology and recharge regimes. But a linkage to agronomy programmes such as integrated pest management, vermiculture and rice intensification at field scale is essential if water management is to prove effective at scale. Evidence from related initiatives have indicated willingness of farmers to use improved agrometeorological services/information and be involved in the gathering of local agrometeorological data. More elaborate water accounting at irrigation system and sub-basin level, assisted by periodic satellite overpasses, is making the assessment of consumptive use and irrigation performance possible, together with the regulation of water use rights. The FAO WaPOR portal[10] and the Water Accounting+[11] approach of the International Water Management Institute (IWMI) have proved effective tools. Seasonal comparisons are already assisting national governments with adjustments of water use policies.

- Investment planning in agricultural water management is now much more likely to assess climate risks. In particular, methods of decision-making are being adopted as a means to manage risk from the bottom up by assessing the ‘breaking points’, in particular agricultural systems reliant upon water infrastructure (World Bank, 2016b).

Beyond the generation of relevant information and software/hardware adjustments in existing irrigation schemes, the use of saline water and wastewater, treated to appropriate levels, is being deployed as agronomic techniques and regulatory provisions permit (see Chapter 3). While systems of desalination are energy-intensive, lower marginal costs have triggered use in irrigation where no freshwater alternative exists and markets for early-season horticulture products are favourable. The use of wastewater technology packages is seeing broad application (FAO, 2010) where use can comply with biosafety regulation, such as limiting use to irrigated fodder (see Chapter 5). In addition, partially treated wastewater reuse in agriculture augments supply in otherwise water-scarce areas and also delivers plant nutrients.

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[10] www.fao.org/in-action/remote-sensing-for-water-productivity/en/.

[11] www.wateraccounting.org/index.html.

All adaptation processes involve hydro-environmental and economic trade-offs. For example, the depletion of groundwater storage and degradation of water quality from return flows is becoming progressively concentrated on irrigated land (Böhlke, 2002; FAO/IWMI 2018). There is also concern for the future of marginal producers, particularly smallholders in semi-arid zones, where capital resources and access to market-based solutions such as crop insurance are limited. The use of traditional rainfall-harvesting techniques and aquifer recharge enhancement, including sand dams, have applications in both rural water supply and the development of irrigated production. Such interventions in remote locations are generally labour-intensive and thus may suit local job creation schemes (ILO, 2019). These techniques, when implemented in combination with soil conservation measures through enhanced water management, can extend soil moisture availability to cover critical periods of crop development (e.g. flowering). However, without access to local aquifers that do not drain during dry-season recessions, these measures are still inherently risky if annual rainfall does not allow replenishment.

Adaptation opportunities are scale-dependent and it is important to distinguish between production systems characterized by large-scale, commercial producers in specific food and fodder sectors, as opposed to millions of diverse smallholders with highly distributed and variable access to water. The necessary investment costs may be zero in many cases, such as for adjustments to the cropping calendar. In other cases, such as wholesale protection of irrigation systems to deal with more extreme flood events, investments in additional water control infrastructure can be significant. How the incremental cost of adaptation is financed through individual farmer investment, state subsidy or capital expenditure in rural development is a policy matter that needs to be conformable with technical interventions. From a water perspective, the central concern is whether that level of investment reduces the water resource risk to agricultural producers and all the users of environmental services related to water in the long term.

6.4 Greenhouse gas emissions from agriculture, forestry and other land use

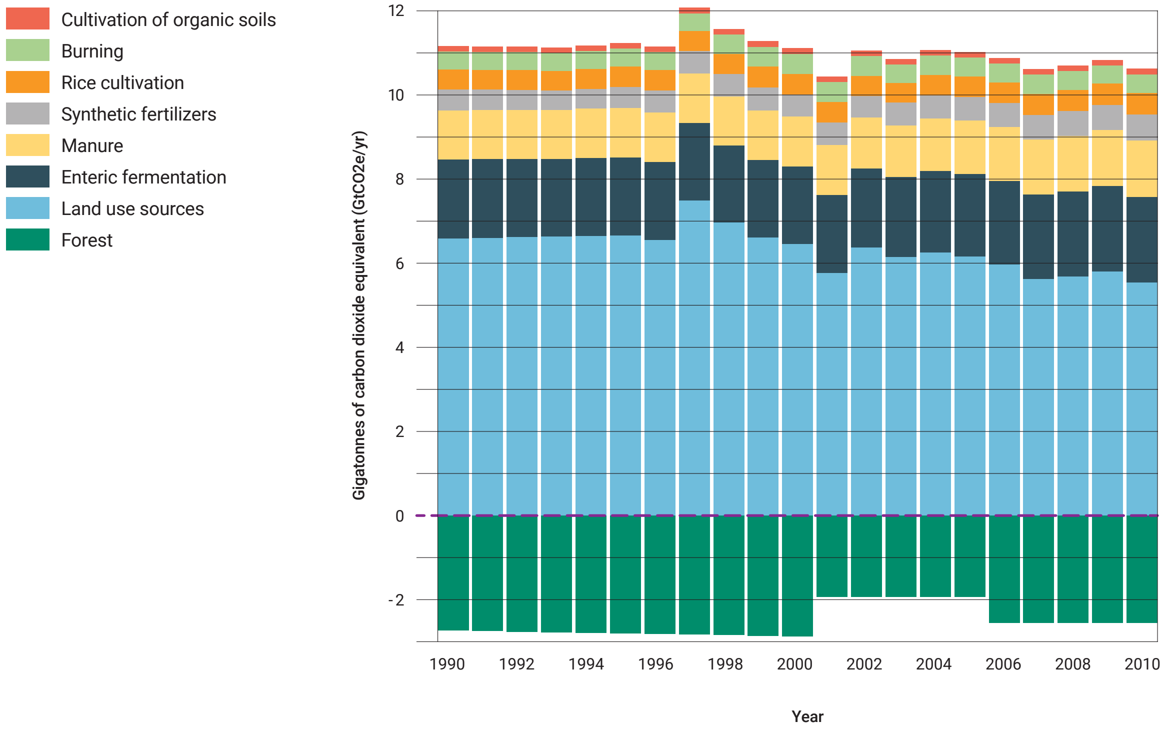
The IPCC Summary for Policy Makers notes: "*Agriculture, Forestry and Other Land Use (AFOLU) activities accounted for around 13% of CO_2, 44% of methane (CH_4), and 82% of nitrous oxide (N_2O) emissions from human activities globally during 2007–2016, representing 23% (12.0 +/- 3.0 $GtCO_2e/yr$) of total net anthropogenic emissions of GHGs (medium confidence)*" (IPCC, 2019b, p. 7).

The relative share of agriculture's GHG emissions has dropped from an estimated 30% at the end of the 20th century to about 20–25% in 2010, largely due to high increases in emissions from the energy sector (FAO, 2017a). The breakdown of emissions from the AFOLU 'sector' is presented in Figure 6.3. Biomass growth in forested areas removes GHG from the atmosphere and makes a net positive contribution of around 2 Gt/yr to carbon sequestration, therefore showing as a negative emission in Figure 6.3. However, the removal of GHG by forested land is estimated to have fallen from some 2.8 Gt/yr in the 1990s to 1.8 Gt/yr by 2014, as burning and conversion of forested land for grazing, palm oil and grain staples has accelerated (FAO, 2016a).

Agriculture (excluding forestry and land use) is estimated to make a net contribution of ~6.2 $GtCO_2e/yr$, accounting for between 10 and 12% of total anthropogenic GHG emissions, which is estimated at around 51 $GtCO_2e/yr$ (IPCC, 2019b). Nonetheless, net agricultural emissions are expected to grow further. Under plausible development pathways, agriculture is only expected to reach some 21–40% of the assumed reduction of ~1 $GtCO_2e/yr$ by 2030 to reach the Paris Agreement target (2°C above pre-industrial levels) by 2030 (Wollenberg et al., 2016). Figure 6.4 points to the significance of enteric fermentation from livestock as a source of methane in GHG emissions (Gerber et al., 2013). The patterns of GHGs from global livestock chains show clear differences between production activities and products.

The risks of draining natural wetlands and wetland forests to convert to dry-foot crops or palm plantations have been evident. The release of carbon stored in wetland peat accumulations in Southeast Asia as a result of deliberate fires to clear land for plantation development has been confirmed by recent research

Figure 6.3 Agriculture, Forestry and Other Land Use (AFOLU) emissions



Note: 'Manure' includes 'manure left on pasture', 'manure management' and 'manure applied to soils'; 'burning' includes 'burning – crop residues', 'burning – savannah' and 'crop residues'.

Source: FAO (2017a, fig. 4.1, p. 40).

(Wiggins et al., 2018). High-resolution Light Detection and Ranging (LiDAR) mapping has pointed to the influence of drainage in exposing peat soils to the risk of combustion (Konecny et al., 2016). However, the release of carbon from peat combustion can also occur on drained organic soils in temperate latitudes. Drainage management is therefore an area that should not be ignored, particularly if the productivity of wetlands and wetland forests is also taken into account.

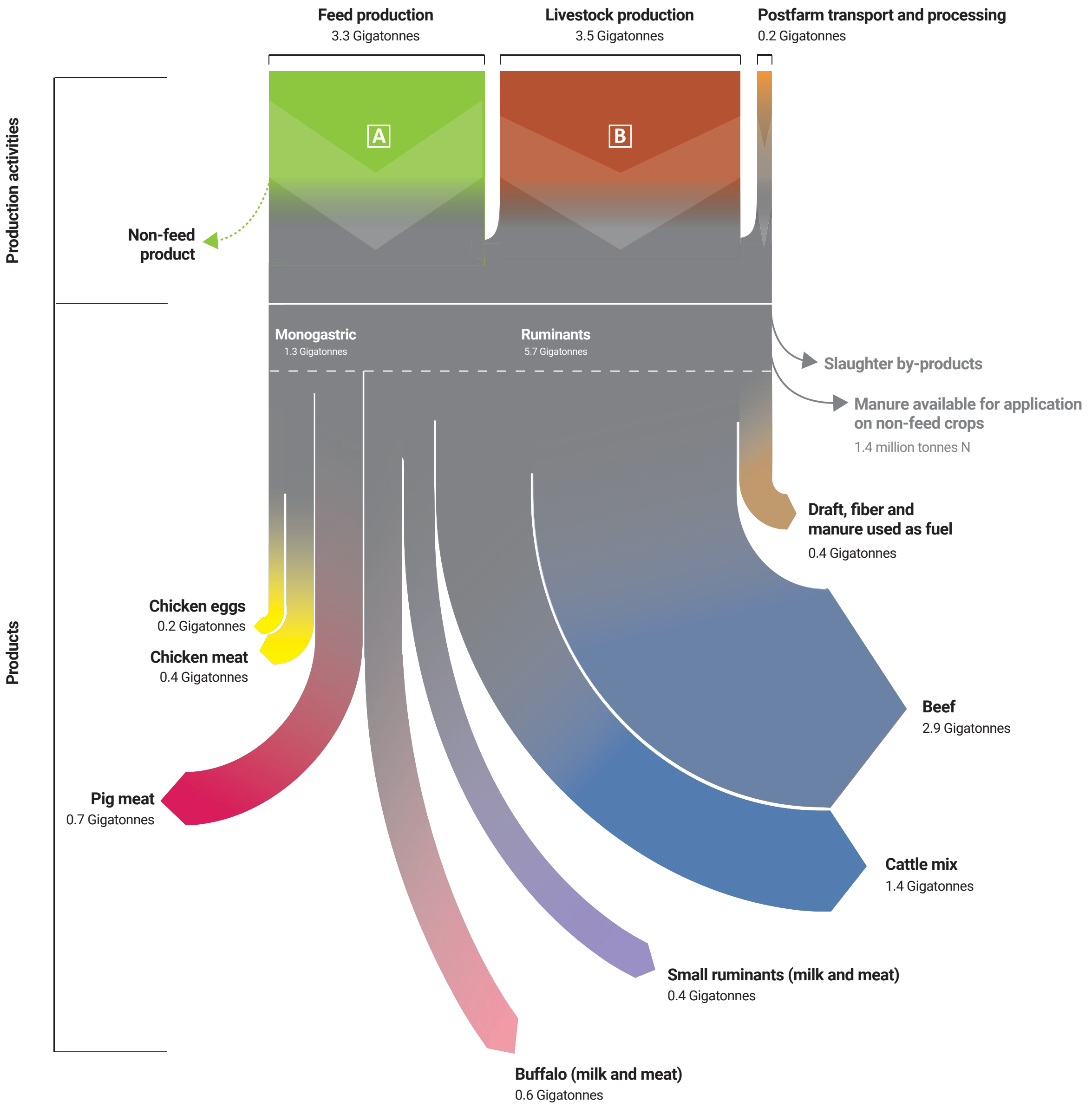
6.5 The role of agricultural water management in mitigation

6.5.1 Scope for mitigation

Agriculture has two main avenues for mitigation of GHGs: carbon sequestration through biomass accumulation above and below the ground, and emission reduction through land and water management, including adoption of renewable energy inputs such as solar pumping. Agronomic practice to mitigate the emission of GHGs is linked primarily to afforestation and drainage control of organic soils that might otherwise decompose or even combust if drained extensively and cleared by burning. Both interventions have direct consequences for water management.

The largest mitigation potential from forestry is expected from reducing emissions attributable to deforestation and forest degradation. More than 90% of national REDD+ results (United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) reported to the United Nations Framework Convention on Climate Change (UNFCCC) come from reduced deforestation (FAO, 2016a). In the long term, progressive carbon sequestration from afforestation and reforestation is expected to maintain a similar level of mitigation (Griscom et al., 2017).

Figure 6.4 Greenhouse gas emissions from global livestock supply chains



Source: Gerber et al. (2013, fig. 5, p. 18).

However, in terms of equivalent tonnes of CO_2, the largest contribution to agricultural GHG emissions is made by the release of livestock methane through enteric fermentation and manure deposited on pasture – some 3.5 Gt CO_2e/yr (see Figure 6.3). It might not be immediately apparent that extensive rainfed pasture constitutes a problem from a water management perspective.

Trends in zero grazing of livestock, particularly in the Middle East and the Midwest of the USA, are already resulting in the concentration of water demand in fewer locations, straining local and regional aquifer systems, notably groundwater, for the production of fodder and the watering/cooling of livestock (Shah, 2009; Alqaisi et al., 2010; Dieter et al., 2018).

The extent of cultivated land in the rainfed subsector, comprising 11 million km^2 under temporary rainfed crops and 33 million km^2 under permanent meadows and pastures (FAOSTAT, n.d.), presents a prime opportunity for improved soil management to retain soil moisture and promote root growth, thereby making net additions to the soil carbon pool (effectively sequestering carbon). However, the scope to make positive net reductions will be limited by the availability of soil moisture to establish a store of year-round soil organic material under cropped regimes and sufficient soil moisture and shallow groundwater to establish woody vegetation. Irrigation and water harvesting in dryland areas already contributes to carbon sequestration on land that would otherwise be barren and depleted of organic carbon through desiccation and wind erosion. The extension of irrigated production in drylands can be taken as a future contribution to carbon sequestration but is extremely limited by long-term availability of freshwater.

6.5.2 Taking practical agricultural water management solutions for mitigation to scale

The functional links between soil organic matter and soil moisture provide the main area for mitigation opportunities. Conservation agriculture techniques and their regional variants are being promoted on the basis of a no-regrets approach to improve productivity as much as reduce GHG emissions (FAO, 2016b). However, the economic feasibility of such measures has to be judged carefully. Scaling of investment and application of some techniques such as no-tillage and seed drilling is not possible on all soils. For example, the initial state of soil health in the marginal/skeletal soils most affected by aridity may not be amenable to substantial improvement without high levels of nutrients and imported organic material together with periodic irrigation.

Widespread adoption of conservation agriculture is dependent upon the type of crop being grown and the availability of seed drills, harvesting mechanization and the availability of residue biomass for mulching. Real yield increases are then dependent upon the availability of improved seed varieties. Lastly, the increased labour inputs or labour substitution through farm mechanization and changes in cultivation practice have to be available and affordable. Underpinning such adoption is the role of extension agents, input providers, farmer field schools and integrated pest management practitioners.

Specific agroforestry and agronomic practice targeted at carbon sequestration and emission reduction can be grouped into five main types:

- Agroforestry, which exists in multiple forms, from productive trees for fruit products, to native trees for wind breaks and shade, to extensive plantations for energy feedstock. Agroforestry can have positive impacts on soil water infiltration, soil water storage, groundwater recharge, runoff and erosion control, soil nutrient cycling, and biodiversity (FAO, 2018e). In pure water budget terms, the conversion of cultivated land or grassland to afforested land will increase consumptive use, particularly if high growth rates are achieved (Hofer and Messerli, 2006; Pugh et al., 2019). However, the climatic context must also be taken into account and in temperate zones where forests attract high levels of occult precipitation and bind upland soils, forested catchments may be promoted/protected as a mitigation measure, since they can also sustain higher levels of baseflow for urban water supply (Ellison et al., 2017).
- Treatment of degraded dryland soils through active drainage management (contour bunds, tree pits, etc.) and uptake of no-tillage systems to reduce release of sediment and nutrients have been effective in bringing about temporary increases in soil organic carbon. Such treatment at scale can also produce a positive effect downstream by attenuating and diffusing small flood peaks. The key is in maintaining soil moisture deficits at tolerable levels for plant growth and improving soil structure and hydraulic conductivity to increase infiltration rates, promote deep percolation and direct recharge to aquifers.
- 'Mild' alternate wet–dry cultivation of rice has been shown to reduce methane emissions, maintain yields and potentially reduce water demand by up to 24% when compared with continuous flooding (Corrijo et al., 2017). Other co-benefits can include reductions in pumping costs and lower arsenic concentrations in the grain. However, this has to be set against increased emissions of N_2O from periodically dry soil surfaces, a reduced rate of nitrogen being forced into the root zone (as a result of submergence), loss of aquaculture and related ecosystem functions, and the reduction in weed suppression and groundwater recharge associated with continuous flooding.
- Afforestation to sequester carbon may have advantages since regrowth appears to have higher sequestration potential compared with mature forest cover (Pugh et al., 2019). Again, there are trade-offs in river basins where upstream forest regrowth will increase water consumption in transpiration and can reduce downstream flows. There is also the additional consideration that in semi-arid zones where water tables are moderately deep, additional water inputs may be required to initiate growth. More moderate carbon sequestration through the adoption of agroforestry techniques may be viable where shade is beneficial to field or perennial crops.

- Emerging solar pumping technologies (and related energy contributions to supply grids) and their application to farm production can play an important role in mitigating GHG emissions (Box 6.4). Supplying power and energy is critical to the development of rural economies, and the degree of this dependence is indicated by the level of energy subsidies to highly productive groundwater-reliant areas in India, which has resulted in bankrupt power supply utilities (Shah, 2009). Despite higher capital outlay costs compared with diesel equivalents, the prices of solar photovoltaic system are dropping and evidence of large-scale uptake has started to emerge (Zou et al., 2013). However, in terms of water management, the location of solar-powered pumping may prove critical. In zones with shallow water tables (e.g. East Ganges, parts of Indus basin), the combined benefit of drainage/salinity control and irrigation water supply may need to be offset against the hazards of mobilizing natural groundwater, notably the mobilization of arsenic from tainted aquifers. Also, the wholesale substitution of the energy source to boreholes for farmers currently enjoying subsidized thermal power will not always be technically or financially viable, particularly if powering deep borehole pumps requires three-phase power supply. If not adequately managed and regulated, such technology also comes with the risk of supporting unsustainable water use (FAO/GIZ, 2018).

6.6 Conclusions

The agricultural 'responses' to a changing climate will be led by climate information applied at appropriate scales in ways that appeal to different farming communities. In this sense, adaptation and mitigation measures will be information-rich rather than hardware-intensive.

Focusing only on the water variable in agriculture will not necessarily produce desired results in agricultural productivity. Broader consideration of water in relation to other inputs, through a package of climate-smart measures, is necessary. The adjustments need to match the scale of the hydrological system if they are to produce positive outcomes in agricultural system performance (in relation to climate variability) and lead to net reductions in GHG emissions.

Box 6.4 Uptake of solar pumping

Following various successes of solar-based irrigation projects (SIPs) in Africa and Asia, the investment in solar technology to transform agricultural development is rapidly expanding, providing a cost-effective and sustainable energy source to secure food production and sustain livelihoods (FAO/GIZ, 2018). Ensuring environmentally sustainable SIP development, both on and off the grid, will require stronger regulatory frameworks and policies, given the current near-zero cost of water lifting (Closas and Rap, 2017). In India, from just around 18,000 in 2014–2015, SIPs have increased to nearly 200,000 in recent years, an annual growth rate of 68%. The piloted Solar Power as a Remunerative Crop (SPaRC) model in Gujarat provides smallholder farmers with a remunerative incentive (US$109.7/MWh) to sell solar energy to the grid in an attempt to reduce groundwater abstraction for irrigation (Shah et al., 2018). The Indian Government has incorporated the model in its US$21 billion KUSUM (Kisan Urja Suraksha evam Utthan Mahabhiyan – Farmer Energy Security and Development Mission) scheme, which aims at installing two million SIPs.

Several government and donor initiatives are promoting SIPs through various subsidy modalities with the aim of reaching the poor. Examples are the support for 50,000 SIPs by 2025 under a 50% subsidy and 30% loan modality in Bangladesh (Verma et al., 2018), finance modalities adapted to female land ownership to support the growing feminization in agriculture in Nepal (Mukherji et al., 2017), and collective solar modalities to support landless and marginalized farmers in India (Sugden et al., 2015).

Solar potential has not gone unnoticed in Africa. In Morocco, Crédit Agricole combines subsidies for solar energy with drip irrigation, in a programme of less than US$220 million, to promote sustainable water use. The scaling of off-grid solutions in Sub-Saharan Africa has seen a slower pace compared to other regions, despite its huge potential and successful pilots (FAO/GIZ, 2018; Otoo et al., 2018). In Ethiopia, for example, solar photovoltaic pumps for irrigation could transform 18% of the rainfed agricultural land (Schmitter et al., 2018). Identified barriers for solar scaling in Sub-Saharan Africa are related to weak supply chains, high import taxes and lack of financial mechanisms (FAO/GIZ, 2018).

The signals from general circulation models indicate that despite the elevated CO_2 fertilization boost to yields, many productive farming systems in temperate and semi-arid zones will be operating at agro-climatic margins in terms of heat and moisture. This will impact farmers who may have to invest in measures to adapt or exit agriculture and find alternative sources of livelihoods as a result of water scarcity. Sustainable water management will be the primary adaptation measure where shifts in seasonal rainfall patterns and higher temperatures make rainfed agriculture too unreliable to meet levels of demand for food staples. As a result, the pressure on the freshwater resource base is expected to intensify and agronomy is expected to become more productive with respect to water as the impacts of aridity and water scarcity are felt by producers. Widespread adoption of conservation agriculture approaches on rainfed land is expected to be a longer-term response that reduces inputs, sequesters carbon, and favours soil moisture retention and percolation in order to enhance freshwater storage and water quality.

To be climate-smart, a first-order requirement is the extension of agrometeorological services and information to farmers who would otherwise have no reliable access. Adjustments in local and basin agricultural water management will be led by software: climate information tools suited to specific sets of producers. In many cases, efforts will be needed to counteract gender bias and ensure that female farmers have equal access. Where withdrawals are intensifying, operational (field-based) water accounting will complement these services in order to prepare annual crop plans and manage surface and groundwater flows/storage/allocation. Adoption of technology packages and extension/farmer field school support have to yield positive returns to farmers, bearing in mind that the institutional context is highly variable and users may be indifferent to guidance if benefits are not demonstrable or sustained. To take CSA to scale, a set of technical water policy messages can be summarized at respective levels.

At national/international levels:

- Promote agro-climate-based tools to anticipate increased climate risks (rainfall intensity, duration and frequency, as well as diurnal temperature range, humidity and evaporative power);
- Extend incentives linked to adaptation and mitigation practices, including weather-related crop insurance;
- Enhance water governance measures that anticipate allocation under scarcity; and
- Overcome institutional/social rigidity with respect to adaptation and mitigation measures.

At basin levels:

- Declare accurate operational agricultural water accounts to place against other sectoral claims and identify the scope for adjustment of baseflow management to sustain instream benefits (including fisheries and recharge) under climate variability; and
- Effect transition from conjunctive use to conjunctive management in order to keep groundwater systems in play.

At irrigated-system levels:

- Implement climate-proof infrastructure and field production systems, including phasing in of irrigation and drainage system redundancy on the basis of no-regrets measures; and
- Enhance irrigation management capacities of operational staff and user groups through access to climate service and CSA practices.

At farmer levels:

- Deploy packages of CSA and irrigation through socially inclusive farmer field school approaches; and
- Carefully assess labour and mechanization costs, including monitoring and pumping/pressurizing technologies, and link to term (fixed period) finance mechanisms.

At producer organization levels:

- Advocate models for sustainable intensification and emissions reduction within specific crop sectors.

7

Energy and industry

Aerial view of a water treatment plant.

UNIDO | John Payne

With contributions from: Christian Susan (UNIDO); Orlaith Delargy (CDP); Stephan Hülsmann and Edeltraud Guenther (UNU-FLORES); Mário Franca and Miroslav Marence (IHE Delft); and Neil Dhot (AquaFed)

This chapter identifies the risks, challenges and opportunities for water-related adaptation, mitigation and resilience to climate change for energy and industry.

7.1 Context

The industry and energy sectors prefer to operate in an atmosphere of certainty – and though climate change is certain, its impacts on water are particularly uncertain. Given that industry (including the energy sector for thermoelectric and nuclear power plant cooling) withdraws 19% of the world's freshwater resources (AQUASTAT, n.d.), and more recently energy alone was estimated as taking about 10% (IEA, 2016), the pressure of this unpredictability is a serious challenge and one that is mounting as emissions of greenhouse gases (GHGs) are increasing.

Moreover, the industry and energy sectors' share in global water demand (Table 7.1) has been projected to grow to 24% by 2050, with the biggest absolute increases in Asia and Europe (mainly for industry), and North America being the only region predicted to show a decrease (Burek et al., 2016). Projections by the International Energy Agency (IEA) using their main scenario (New Policies)[12] anticipate that global water withdrawals by the energy sector will increase by less than 2% by 2040, but consumption will increase by nearly 60% (IEA, 2016). In water-stressed areas this will contribute to increasing scarcity, as less water will be returned to the hydrological cycle for other sectors to use.

Table 7.1 Industrial water demand, by continent, 2010 and 2050 (*middle of the road* scenario)

	2010 (km^3/yr)	Share of continent's total water use	2050 (km^3/yr)	Share of continent's total water use	Change rate (2050 as % of 2010)
Africa	18	8%	64	18%	353%
Asia	316	10%	760	19%	240%
North and Central America	229	35%	182	27%	80%
South America	31	19%	47	21%	153%
Europe	241	54%	325	58%	135%
Oceania	2	5%	3	7%	144%
World	**838**	**18%**	**1381**	**24%**	**165%**

Source: Adapted from Burek et al. (2016, table 4–10, p. 62).

Without adaptation and mitigation measures, substantial repercussions are likely not only in low- and middle-income countries but also in high-income ones, across all segments of society and up and down value chains.

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[12] *"Our main scenario in WEO-2016, the New Policies Scenario, incorporates existing energy policies as well as an assessment of the results likely to stem from the implementation of announced intentions, notably those in the climate pledges submitted for COP21."* (IEA, 2016, p. 31).

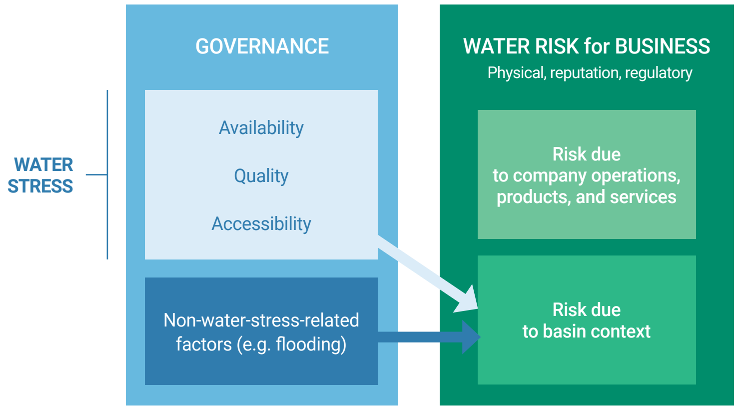
7.2 Challenges and risks

According to the World Economic Forum, since 2014 extreme weather events have been the first or second global risk in terms of likelihood, and water crises have been in the top five in terms of impact (WEF, 2019). Water-related shocks in emerging economies have already led to massive insurance losses, supply chain failures and price shocks with global implications. Failure to address these risks could lead to a dramatic drop in business investment, with stark consequences for enterprise and for development (IIASA, n.d.). Water challenges and business risks will become apparent for the energy and industry sectors, and will be generally similar for both. The four top water risk drivers for companies recently reported are water scarcity, flooding, drought and water stress (CDP, 2017a).

7.2.1 Water Challenges

Water Stress: The reliability of water supply in terms of availability (quantity), quality as affected by pollution, and accessibility (allocation, competition and conflict) are key to the continued and successful functioning of business (Figure 7.1). These factors are complicated by the uncertainty and unpredictability, as well as the increasing variability, of both surface water replenishment and groundwater recharge as a result of climate change. A simplification indicates that dry areas will get drier and it is in these subtropical regions that water stress, expressed through physical drought, will likely be felt the most severely. This will have impacts on the energy generation and industry sectors, including their supply chains, as heavy water users.

Figure 7.1 Water stress and risks for business



Source: Adapted from CEO Water Mandate (2014).

Energy generation is potentially impacted by all types of water stressors (Table 7.2) (IEA, 2012). For example, river and water levels can fall below intakes at thermal stations and hydropower facilities, stopping operations. Moreover, increased water temperatures affect cooling, lowering thermal efficiency which reduces or, if exceeding critical thresholds, even halts power output. The exposures exist in many different geographic areas and for many forms of energy production. Even with good overall water availability, seasonal variations can be troublesome, and countries with a lot of thermal generation capacity using once-through cooling and/or hydropower are especially susceptible. For electricity generation on a global scale, streamflow and temperature changes will vary as a result of climate change: accounting for time and climate factors, climate change could produce a reduction in hydropower in the 2050s of 1.2 to 3.6%, especially in Australia and South America, and a 7 to 12% in thermoelectric power in most regions (Van Vliet et al., 2016).

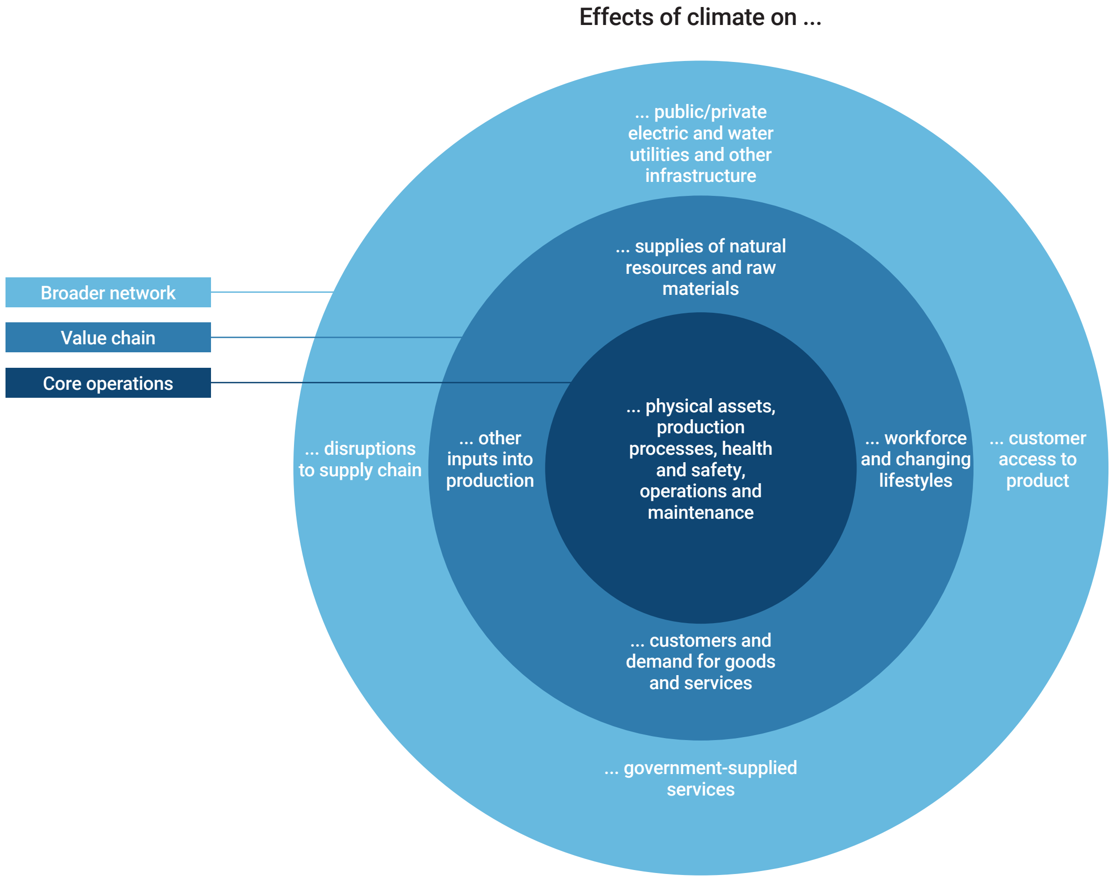
Table 7.2 Examples of water impacts on energy production

Location (Year)	Power generation
Kenya (2017)	The drought that began in 2017 has caused repeated power shortages and higher electricity prices.
USA (2016)	The Hoover Dam's generating capacity was reduced to 30% due to drought.
Brazil (2016)	Drought affected hydroelectric power producers such as the Itaipu Dam, forcing the country to turn to more expensive and polluting thermoelectric plants.
Ghana (2016)	The Akosombo Dam, the country's main source of energy, operated at minimum capacity due to drought.
India (2013–2016)	Water shortages caused shutdowns in 14 of India's 20 largest thermal utilities, costing the companies US$1.4 billion. In 2016, 14 Terawatt-hours of potential thermal power generation were lost – equal to the annual electricity demand of Sri Lanka.
India (2012)	A delayed monsoon raised electricity demand (for pumping groundwater for irrigation) and reduced hydropower generation, contributing to blackouts lasting two days and affecting over 600 million people.
Romania (2011)	State-owned hydropower producer Hidroelectrica cut production by 30% due to depleted reservoirs caused by a prolonged drought.
China (2011)	Drought limited hydropower generation along the Yangtze River, contributing to higher coal demand (and prices) and forcing some provinces to implement strict energy efficiency measures and electricity rationing. In Yunnan Province, extreme drought cut hydropower output by half and forced 1 000 dams to suspend operations.
Viet Nam, Philippines (2010)	The El Niño weather phenomenon caused a drought that lasted several months, reducing hydropower generation and causing electricity shortages.
Southeast USA (2007)	During a drought, the Tennessee Valley Authority curtailed hydroelectric power generation to conserve water and reduced output from nuclear and fossil fuel-based plants.
Midwest USA (2006)	A heat wave forced nuclear plants to reduce their output because of the high water temperature of the Mississippi River.
France (2003)	An extended heat wave forced electricity company Électricité de France (EdF) to curtail nuclear power output equivalent to the loss of 4–5 reactors, costing an estimated €300 million to import electricity.
	Primary energy production
China (2008)	Dozens of planned coal-to-liquid (CTL) projects were abandoned, due in part to concerns that they would place heavy burdens on scarce water resources.
Australia, Bulgaria, Canada, France, USA	Public concern about the potential environmental impacts of unconventional gas production (including on water) has prompted additional regulation and, in some jurisdictions, temporary moratoria or bans on hydraulic fracturing.

Sources: Based on IEA (2012, table 17.3), with complimentary information from Wang et al. (2017) and Kressig et al. (2018).

Extreme events: Flooding and drought are water-related effects exacerbated in time and space by climate change. They are increasingly frequent and intense, with consequently more pressure on power generation and industry. For instance, the 2011 flooding in Thailand affected 800 facilities employing 450,000 workers and caused a global disruption in the supply of disc drives (Winn, 2011). Moreover, slow onset disasters such as sea level rise will affect extensive coastal areas where energy utilities and industry are commonly located.

Figure 7.2 Categories of climate change impacts on businesses



Source: Freed and Sussman (2008, fig. 2, p. 13).

7.2.2 Business risks

The water-related effects of climate change generate risks to business and power generation from several perspectives.[13] Climate change impacts (many related to water) are illustrated for the mining and metals sector in Figure 7.2, where three levels of broadening risk are shown. The inner level is site-specific primary impacts to core operations; the next level includes risks that affect the value chain, such as the ones regarding raw materials; the outer level shows third-party impacts, including energy supply (ICMM, 2013).

Climate change can also be a ‘threat multiplier’ for business risks. For instance, water scarcity connects and affects energy, industry and food. Businesses will face difficulty in addressing and managing all these facets. Indeed, the majority of risk for industry and power generation originates outside the fence line and is beyond their sole control and influence (Table 7.3).

Operational risks: Water stress can stop manufacturing or energy generation, purely through a lack of water. Impacts will also carry into operational aspects, affecting the supply of raw materials, disrupting supply chains, and causing damage to facilities, equipment, and also infrastructure. This in turn could interrupt transport and affect energy (e.g. transmission lines and pipelines) and communications. The results may be reflected in human terms with unsafe working conditions, health effects, more absenteeism and lower productivity. Moreover, major climate change may produce fast changes in consumer demand, such as for energy. To address that increased demand, usually water for generation will be needed.

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[13] The information in this subsection is mainly from UNGC/UNEP/Oxfam/WRI (2011), Schulte (2018) and OCCIAR (2015).

Table 7.3 Climate change risks for some major business sectors

Business sector	Illustrative risks	Concerns
Energy and utilities	Reputational risk; physical risk due to extreme weather events; peak demand could outstrip capacity; hot weather may reduce efficiency of extraction.	• Potential physical damage to personnel and equipment, potential disruption of the production activities of offshore installations. • Significant climate changes (mainly from temperature, but also wind and water conditions) from one year to another can cause substantial variations in the balance of supply and demand for electricity and gas. • Water shortages and heat waves can reduce hydroelectric power production.
Manufacturing and consumer goods	Higher prices of raw materials and freshwater; higher energy prices; unanticipated changes in customer preferences; supply chain disruptions.	• Dramatically rising energy prices will have a negative impact on operating costs. • Reduced availability, supply and quality of raw materials and freshwater. • Production bottlenecks due to functional failures in supply chains.
Mining and industrial metals	Regulatory risk; vulnerability to energy and water shortages due to intensity of use; rainfall and flooding leading to potential overflow of storage reservoirs containing contaminants.	• Increasing regulatory pressure will impact the steel industry in terms of impacts on the process, location of facilities and availability of raw materials. • Concerns about energy security where power comes from large hydroelectric plants via national power companies, and water security.
Food and beverage	Water scarcity; crop damage due to weather extremes; increased exposure to new pests and disease; transportation problems.	• Water scarcity is the primary vulnerability. • The impact of climate change on agricultural products is increasing.

Source: Adapted from UNGC/UNEP/Oxfam/WRI (2011, table 1, p. 21).

Regulatory risks: Adaptation to climate change will promote corresponding regulatory changes governing water use, water allocation, pricing, effluent, development, disaster risk and so on. Compliance is likely to affect the energy and industry sectors by increasing operational costs and requiring additional reporting on their climate risks and adaptation measures. Yet conversely, regulatory risk is arguably higher where there are inadequate regulations and control on water resources, resulting in uncertain circumstances.

Reputational risks: When people, particularly as consumers but also as investors and stakeholders, become more aware of climate change and the ways it affects them, they may look more critically at corporate operations and behaviour, and at mitigation and adaptation measures with respect to GHG emissions and water use. Negative perceptions of companies may result in a range of consequences, from bad press and poor reputation to being unable to operate.

Other risks: Financial, market and political risks driven by water are also part of the overall equation. For instance, companies may find financing increasingly difficult if they locate to low-income countries prone to water stress, aggravated by climate change. Moreover, demographic changes and population movement related to water issues can change the customer base. This might have a positive effect by increasing demand for more energy- and water-efficient products, but spending power may be reduced in low-income countries as more money will go to the process of adapting to increasing water stress. The struggles with climate change and its associated issues, including water, may produce political instability and even conflict. This presents not only uncertainty, but even threats to business, particularly those that are heavily invested in a particular country.

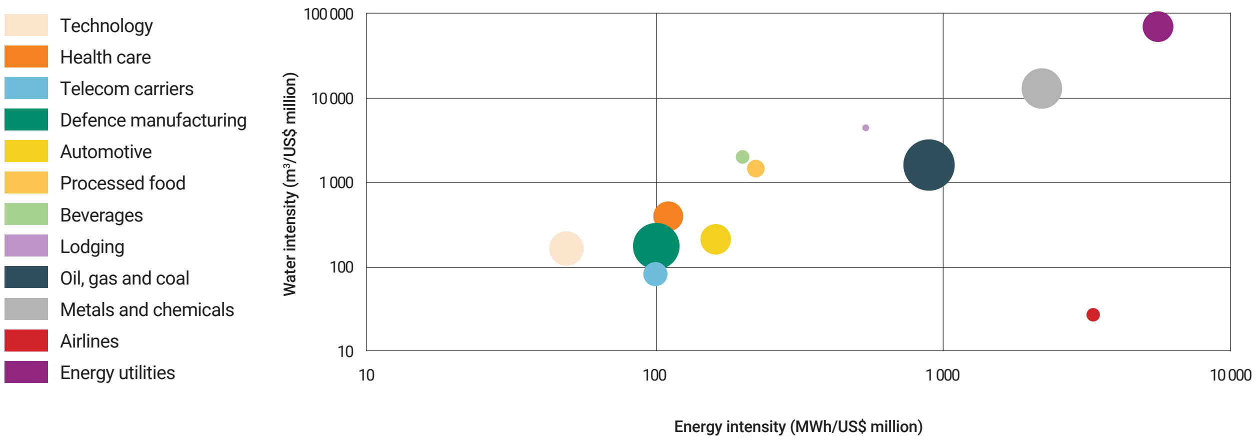
7.3 Reactions and opportunities

Notwithstanding the increasing recent emphasis on climate change impacts within the energy and industry sectors, the issue has been recognized for some time. This is witnessed in water-related initiatives by many companies working with The CEO Water Mandate and the CDP (the global disclosure system for investors, companies, cities, states and regions, formerly known as the Carbon Disclosure Project), as well as in early reports from organizations such as the World Business Council for Sustainable Development (WBCSD, 2009) and the United Nations Global Compact (UNGC/Goldman Sachs, 2009). The private sector is 'waking up' to the importance of water security and recognizing the significant impacts climate change could have on commercial success (CDP, 2017a). A large and growing number of companies are now acting to achieve positive outcomes, for example by reducing the amount of water used in manufacturing, which in turn reduces energy required for water treatment. Reactions to climate change broadly encompass measures involving mitigation or adaptation and sometimes a combination of both. For companies, there are consequences attached to action as well as inaction. Such consequences can be monetarized in a net effect by comparing the costs of action (e.g. flood protection of buildings) that might be shared or shifted (e.g. to insurance) with the cost of inaction (e.g. energy disruption due to floods) (ISO, 2019).

Over 50 corporate signatories to the Business Alliance for Water and Climate (BAFWAC)[14] report manage and act on their water and climate impacts through CDP (Box 7.1). CDP annually benchmarks each of these companies to track their progress towards a low-carbon, water-secure future. Overall, the data suggest that companies cannot take action on these issues in silos.

Global decarbonization efforts could depend on how companies manage water (CDP, 2016). In 2016, CDP reported a cost of US$14 billion from water-related impacts of climate change, a fivefold increase from the previous reporting year. Moreover, CDP analysed emissions reduction activities disclosed by companies and found that nearly a quarter (24%) of these activities depended on having a reliable supply of water for their success. These activities, which included improvements in energy efficiency and low-carbon energy purchases, could cut 125 million metric tonnes of CO_2 emissions annually – equivalent to closing 36 coal-fired power plants for a year. Furthemore, over half the companies reported lower GHG emissions through improved water management. Figure 7.3 shows the relationship between water and energy intensity for some major industries.

Figure 7.3 Water and energy intensity of major industries



Note: Bubble area proportional to total industry revenue.

Source: Metzger et al. (2016, fig. 2, p. 4).

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[14] BAFWAC was jointly launched by CDP, The CEO Water Mandate, SUEZ, and the WBCSD in December 2015 and has since been endorsed by the United Nations Framework Convention on Climate Change (UNFCCC). Each year, BAFWAC tracks and reports the progress of signatory companies towards the commitment at the UNFCCC Conference of Parties (COP). BAFWAC will dissolve at the end of 2020.

Box 7.1 Companies and climate change

Companies report significant business risks from water and climate issues.

- Colgate Palmolive reports that in 2016, El Niño caused a severe drought in Southeast Asia, impacting palm fruit yield and reducing palm oil production by 27% in the first half of the year versus the same period in the previous year. These changes impacted Colgate's supply chain, and the company now assesses the future implications of water scarcity on key commodities.
- Climate change affects the demand for and supply of electricity. French energy supply company ENGIE reports that increasing temperatures in some regions can reduce energy requirements for heating homes and buildings, and therefore the demand for ENGIE's services. On the supply side, water is essential to ENGIE's hydropowering processes, and significant changes in precipitation, such as droughts, will substantially affect the company's electricity production.
- Other companies are working to reduce their dependence on water resources in recognition of a changing climate. Ford Motor Company set a target of a 30% reduction in water use per vehicle produced by 2020, compared to base year of 3.9 m^3 per vehicle in 2015. The company is making progress towards this target and secured a place on CDP's Water A list in 2018.

Contributed by CDP.

7.3.1 Greenhouse gas mitigation, energy and water use

Energy is in the spotlight of climate change initiatives as about two-thirds of the world's anthropogenic GHGs come from energy production and use (IEA, 2015), and CO_2 emissions from energy rose by 1.6% in 2017 (IEA, 2018). Over 90% of energy's CO_2 emissions are from fossil fuels (IEA, 2015). Since 1988, only 100 private and state-owned enterprises were responsible for 71% of the global industrial GHGs[15] produced by fossil fuel companies (CDP, 2017b). Fossil fuels are primarily used in coal-, oil- and natural gas-fired thermal power generating stations, which are substantial users of cooling water and globally used 58% of total energy water withdrawals in 2014 (IEA, 2016). This is at the heart of the water–energy nexus that is further discussed in a broader context in Chapter 9.

Energy is in the spotlight of climate change initiatives as about two-thirds of the world's anthropogenic GHGs come from energy production and use

There are a number of opportunities to mitigate GHGs and reduce water use at the same time. Reducing energy demand and increasing energy efficiency are starting points – yet global energy demand is projected to increase by more than 25% under the IEA New Policies Scenario. However, the demand would be about twice as much if it were not for improvements in energy efficiency (IEA, 2018).

The most promising direction is the increased use of low-carbon renewable energy technology with little water requirements, such as solar photovoltaic (PV) and wind (Figure 7.4). It has been estimated that in 2030 these renewable energy sources could be responsible for about a 50% reduction in water withdrawals in the United Kingdom, over 25% in the United States of America (USA), Germany and Australia, and above 10% in India (IRENA, 2015). In the European Union (EU), it was estimated that wind energy in 2012 saved as much water as used annually by seven million people in average households, and by 2030 – with increased deployment replacing some fossil fuel and nuclear generation – the amount of water saved will be approximately three to four times more (EWEA, 2014). These numbers provide an idea of the scale of water savings that could be possible using renewable energy in areas of scarcity in low-income countries as well.

Renewables are primarily a response to clean energy/low-carbon initiatives to reduce CO_2 emissions. In this regard, renewable energy sources do not always reduce water use (IEA, 2016). Sources that use heat, such as concentrating solar power and geothermal, often require cooling water, which drives up

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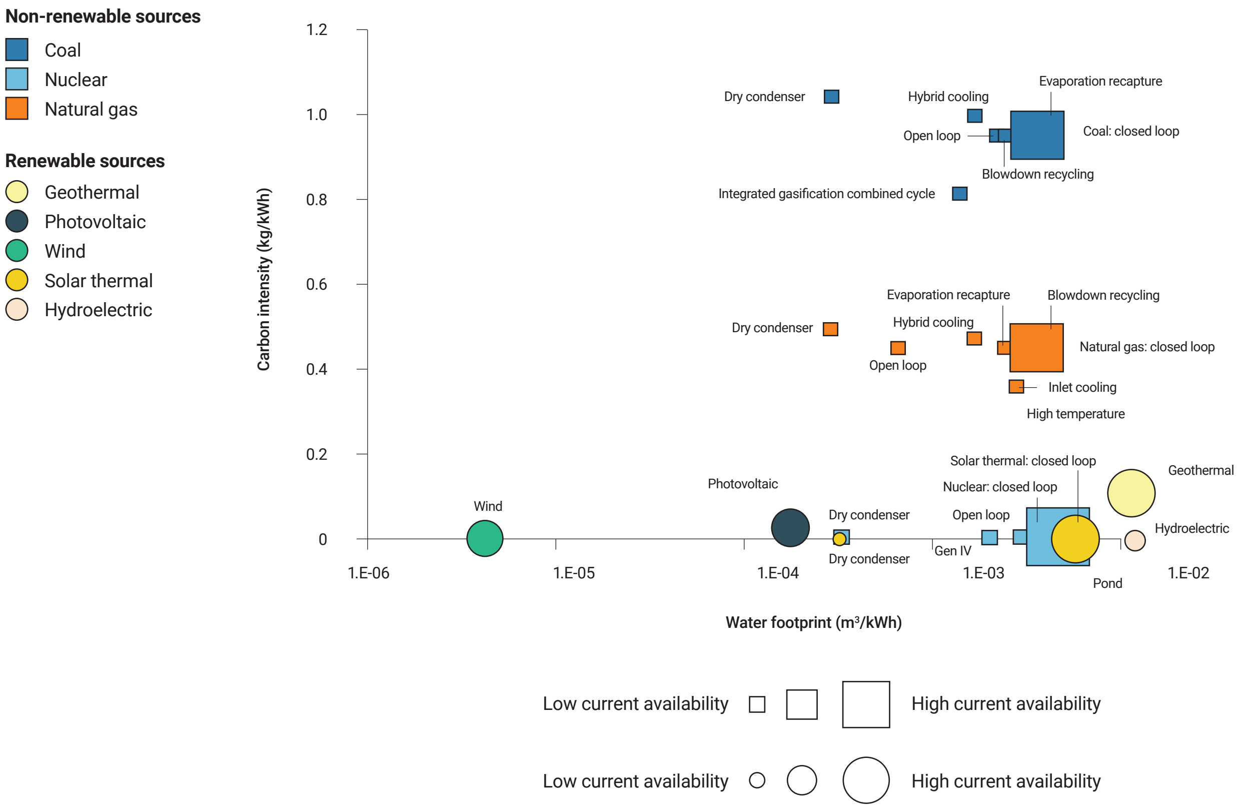
[15] Broadly, this includes the production and downstream combustion of fossil fuels in all sectors, except agriculture for the most part.

Figure 7.4 Indicative water footprint and carbon intensity of energy production, by source



Source: Adapted from World Bank (2016a, fig. 3.1, p. 30). © World Bank, openknowledge.worldbank.org/handle/10986/23665, licensed under: CC BY 3.0 IGO.

consumption. In addition, carbon capture and storage, a technology to extend the life of fossil fuel plants, could nearly double water requirements (IEA, 2016). Similarly, increases in nuclear power production, debatably renewable but seen by some as clean, sustainable energy, will contribute to more water use.

A comprehensive assessment of hydropower as a clean and environmentally friendly energy source needs to take GHG emissions from reservoirs into consideration

Hydropower, which provides 16% of the world's electricity (IEA, 2016) and 70% of renewable power (IEA, 2017a), requires a substantial water supply. However, it differs from cooling water in the sense that, after passing the turbines, the water remains available for other purposes downstream (e.g. irrigation or other hydropower plants). The net water use of hydropower can be reduced if the respective reservoir system is multipurpose. Moreover, hydropower plays a role in integration of other (intermittent) renewables such as wind (Hülsmann et al., 2015). A comprehensive assessment of hydropower as a clean and environmentally friendly energy source needs to take GHG emissions from reservoirs into consideration, which is not an easy task (World Bank, 2017b). Water quality is an additional issue: it relates to GHG emissions, since they were shown to be linked to eutrophication, with methane estimated as comprising 80% of GHG emissions from dam reservoirs (Deemer et al., 2016). Moreover, concentrations of methylmercury increase rapidly in reservoir water after impoundment and persist for a long time, affecting fish and the populations consuming them (Calder et al., 2016).

Maintaining sufficient water levels in reservoirs is critical for maximizing hydropower efficiency, as illustrated by the example of the Hoover Dam in the USA, the capacity of which dropped over 20% as reservoir levels dropped 40 m between 1999 and 2014 due to prolonged drought (Capehart, 2015). Moreover, water consumption by evaporation from large reservoir surface water areas, though difficult to estimate, can be significant in arid and semi-arid areas. For example, the annual mean water budget for Lake Tahoe (USA) includes 60% for evaporation (Friedrich et al., 2018). In areas of existing and projected water scarcity and variability due to climate change, the decision regarding hydropower involves balancing the necessity to store large quantities of water with the water needs of those living and working downstream. On the upside, the flexibility of reservoirs in power generation allows for better integration of variable electricity delivery by wind and solar power into the grid (IEA, 2016). Overall, while hydropower will continue playing a role in climate mitigation and adaptation of the energy sector, the overall sustainability of single projects needs to be assessed, taking account of the above-mentioned points. In addition, ecological and social issues such as deforestation, biodiversity loss, changes in river ecology and hydrology, interference with sediment transport, displacement of people, and impacts on livelihoods must be taken into consideration to avoid repeating known problems (Moran et al., 2018).

Increasing the share of renewables in the final energy mix will have a direct impact on reducing GHG emissions, yet the effect on reducing water use might not be so pronounced. Biofuels, while they offer potential, emphasize the renewable energy conundrum of reducing GHGs and water use (see Chapter 9). The notable exceptions are wind and solar PV, which also have the additional advantage of becoming increasingly competitive with fossil fuel energy generation. From another perspective, while the 10% of water withdrawn globally for energy may look small compared to agriculture, this quantity is still considerable. A saving of 1% per year by better energy use or efficiency could provide water for 219 million people based on 50 L/day, depending on location and other factors. This offers an important opportunity for the energy sector to combat water scarcity while mitigating climate change (United Nations, 2018a).

Industry has a significant role in the mitigation of climate change and the fulfilment of the targets of the Paris Agreement

7.3.2 Decarbonizing industry

Industry has a significant role in the mitigation of climate change and the fulfilment of the targets of the Paris Agreement. Such mitigation efforts would also contribute to reducing water-related climate change impacts over the long term. While creating about 25% of the world's gross domestic product and employment, industry also produced (in 2014) about 28% of global GHG emissions (with CO_2 comprising over 90%), and between 1990 and 2014 industrial emissions increased by 69%.[16] Ammonia, cement, ethylene and steel manufacturing produced nearly half of industry's CO_2 emissions (McKinsey & Company, 2018).

The challenges to decarbonization in these four industries lie in abatement. Feedstocks produce about 45% of the CO_2 emissions, and this can only be lowered by process changes, not by replacing fuel. Also, these industries require high-temperature heat produced by burning fossil fuels (35% of the CO_2 emissions). Opportunities exist to reduce emissions to near zero, one of the most significant being the availability of low-cost zero-carbon electricity[17] for high-temperature electric furnaces. It is estimated that four to nine times more zero-carbon clean energy would be required to fully decarbonize these four industries than the conventionally generated energy they currently use. This would require big changes in energy supply. For example, at present nuclear and hydropower most likely would be the main sources of power that could meet the larger demand. With present prices for commodities, carbon capture and storage is the cheapest decarbonization option, particularly for the cement industry (McKinsey & Company, 2018).

Such industrial GHG mitigation is facing a trade-off with water use, depending on the mix of renewable zero-carbon energy. Water use will increase with nuclear and hydropower, and even carbon capture and storage comes with increased water use.

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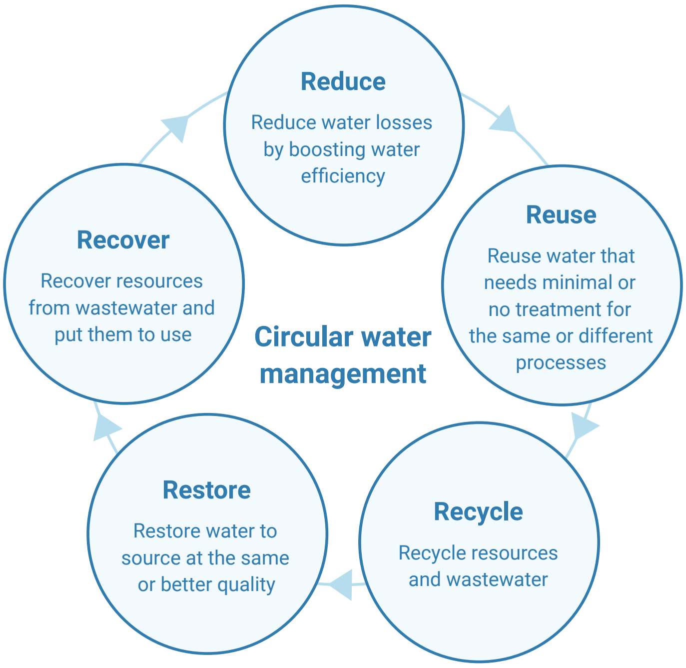
[16] The IEA reports that in 2016, industry's global CO_2 emissions would increase from 19% to 36% if emissions from the electricity it uses were reallocated to it (IEA, 2017b).

[17] Electricity produced from renewables (carbon-free) and at a competitive cost with respect to fossil (carbon) fuel sources.

Figure 7.5 Circular water management



Source: WBCSD (2017, fig. 7, p. 14).

A recent report (UNIDO, 2017a) notes that clean energy in manufacturing can be accelerated through the advent of Industry 4.0[18] and thus contribute to meeting global challenges – such as climate change mitigation – through renewable energy, reduced carbon emissions and optimization of energy use. Opportunities exist to encourage renewable energy and overcome its intermittency if production is matched to peak generation. As such, the industry and energy sectors could integrate with regard to grid load balance to their mutual benefit, resulting in smart grids that use information and communication to manage supply and demand from a variety of generators to many users. This would allow solar and wind to be part of larger networks. The next step might be Virtual Power Plants (VPP), which are mixtures of various energy sources with a cloud-based control centre.

7.3.3 Adaptation and circular water management

With respect to water, climate change adaptation presents industry with two contrasting dilemmas – water stress usually meaning too little water and water disasters resulting in damage from too much. Disasters, particularly flooding, and the regional 'climate proofing' required for all sectors are discussed in Chapter 4. For water stress, industry has a particular and significant contribution to make in reducing water use and becoming more water-efficient. Data indicate opportunities for industry to decrease water consumption overall by up to 50% (Andrews et al., 2011 as cited in WBCSD, 2017).

In preparing for potential water scarcity risks, businesses may adopt circular water management, where the use of water changes from a linear process with increasing contamination (becoming wastewater) into a circular one where water recirculates and loops back for continual use (Stuchtey, 2015). At the plant level, circular water management is typified by the 5Rs approach: reduce, reuse, recycle, restore and recover (WBCSD, 2017) (Figure 7.5). The first three of these Rs are emphasized, as they can reduce costs (Box 7.2). The benefits of treated wastewater are particularly noted by the WBCSD, as they are by the EU in its Water Reuse Action Plan, which includes industry (EC, n.d.). The potential for improvement is significant – in 2010, globally 16% of freshwater withdrawals became industrial wastewater and in many countries only a low percentage is treated (WWAP, 2017).

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[18] Industry 4.0 represents the next (4th) industrial revolution and connects physical industrial production with digital information technology in cyber-physical systems. It is also referred to as the industrial internet (of things), advanced manufacturing or digital manufacturing (UNIDO, 2017a).

Box 7.2 Examples of industrial circular water management

Recycling: The Pearl Gas-to-Liquid (GTL) complex in Ras Laffan, Qatar, is the largest plant of its kind in the world, producing 140,000 barrels/day of oil equivalent. Shell and its partner, Qatar Petroleum, have made a decision to reach zero liquid discharge and recycle 100% of the water in a closed-loop system. Besides water savings, the benefits include strict regulatory compliance, smaller environmental footprint and greater community acceptance (Oxford Business Group, 2014).

Reuse: The Springvale Mine in Lithgow, New South Wales, Australia produces the coal used by the nearby Mount Piper Power Station, which provides approximately 15% of New South Wales' power. The mine water is treated and delivered via a 16 km pipeline to the power station for reuse as cooling water. This ensures environmental and operational compliance in relation to water outflows and, most importantly, enables continued operations of both the mine and the power station (New South Wales Government Department of Planning and Environment, 2017).

Treated wastewater: Tangshan Iron & Steel (TIS) in China plans to build a new coking plant (1.5 million tonnes per year) and a gas liquefaction plant. Being in a water-scarce environment with limited intake and discharge volumes, to support its production TIS has water treatment facilities that allow for 60% reuse of industrial water. In addition, it complies with strict regulation and saves costs through reduced freshwater intake (Veolia, 2014).

Contributed by AquaFed.

The use (or reuse) of the energy contained in flowing water, which is frequently dissipated for operational reasons, contributes to the circularization of the energy cycle. Decarbonization of energy sources includes mining this lost energy, which is hidden in much existing infrastructure used primarily for other purposes (agriculture, water supply, wastewater treatment, industry, etc.). The development of alternative strategies and technical solutions represents an additional low-impact and lucrative solution for energy generation. For example, there is a high potential for hydropower in existing irrigation systems (Marence et al., 2018) and in the USA more than 80,000 non-powered reservoirs offer a possible additional 12 GW of power (Hadjerioua et al., 2012).

7.3.4 Eco-Industrial Parks and the circular economy

Past editions of the *World Water Development Report* have outlined the benefits of water reuse and industrial symbiosis in industrial parks (WWAP, 2017), and effective water and effluent management in Eco-Industrial Parks (EIPs) (WWAP, 2015). Moreover, the WBCSD notes that the 5Rs approach encourages collaboration across sectors, and resource recovery from wastewater is part of circular economy thinking (WBCSD, 2017). The circular economy[19] is concerned with avoiding or minimizing the production of waste, including wastewater.

Within both the concepts of circular economy and green economy, inclusive and sustainable industrial development plays a large role, as promoted through energy and water efficiency measures in programmes such as the Green Industry Initiative (UNIDO, n.d.b) with Resource Efficient and Cleaner Production (RECP). EIPs (Box 7.3) include many of the foregoing efforts in a local circular economy. There are synergies between the green economy and adaptation to climate change (UNGC/UNEP/Oxfam/WRI, 2011).

7.3.5 Corporate adaptation

For climate change, the risk to business associated with water stress is one of the main drivers for water reuse and efficiency (WBCSD, 2017). Depending on the level of treatment required, the technologies are well known and based on variations of, for example, phase separation, precipitation, flotation, biological treatment, filtration and separation, and nature-based solutions (NBS) such as constructed wetlands. In addition, there are many new and emerging technologies. In concert with technology, a facility could

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[19] A circular economy aims to change the existing linear system from raw material to manufacturing to waste, into one where *"everything is reused, remanufactured, recycled back into a raw material, used as a source of energy, or as a last resort, disposed of."* (UNIDO, n.d.a, p. 3).

Box 7.3 Eco-Industrial Parks

The Eco-Industrial Park (EIP) concept is gaining momentum as a form of collaboration between industries located on a common property towards inclusive and sustainable industrial development that goes beyond conventional arrangements (UNIDO, 2017b). EIPs address the environmental, social, and economic pillars of sustainable development, for which water plays an important role. A recent framework for EIPs sets out performance requirements (UNIDO/World Bank Group/GIZ, 2017). One of the key environmental topics is adapting to climate change risks. Water performance standards, involving circularity, for consumption, efficiency and treatment are part of this direction. For example, the targets for wastewater treatment are 95%, with 50% reused responsibly in or outside the EIP. As a result of pilot projects on EIPs in developing and emerging economies, the United Nations Industrial Development Organization (UNIDO) reported that between 2012 and 2018 almost two million m^3 of water were saved per year (UNIDO, 2019).

look at day-to-day operations such as the use of wash water, better monitoring and leak detection. On an expanded scale a company might evaluate its water footprint and include those of its suppliers, which may have far-reaching effects if they are large water users.

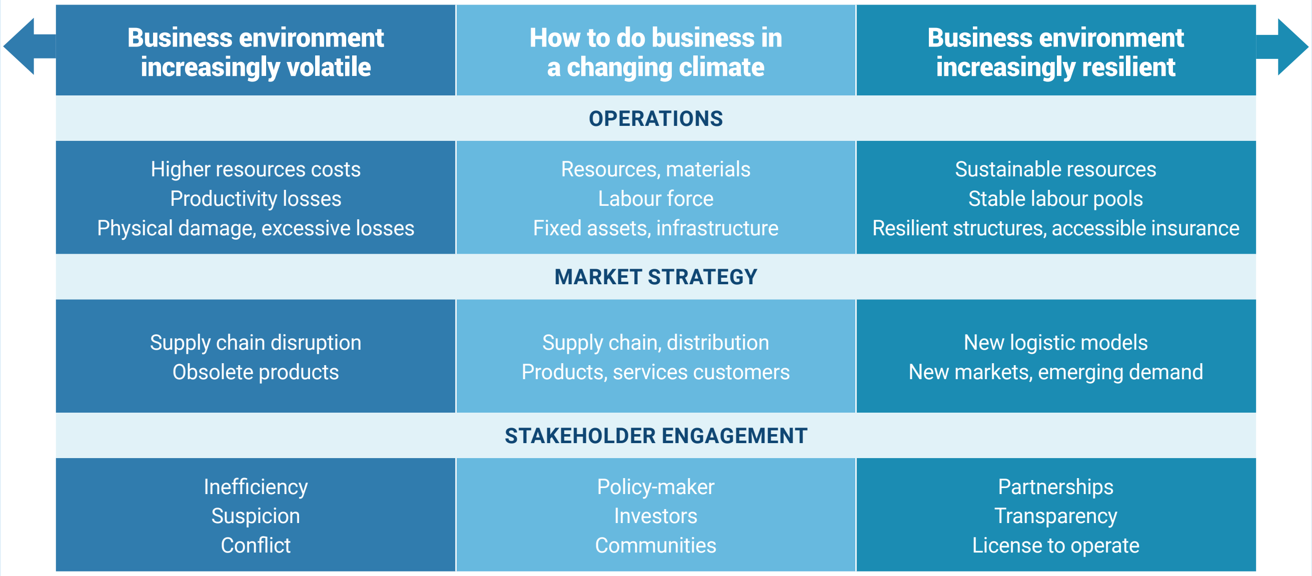
Technology is not a significant barrier to circular water management, unlike regulation, financial resources, awareness and dialogue (WBCSD, 2017). Regulations need revising in order to allow the use of wastewater and to build public confidence. Financial resources reflect the cost and return on investment – low-cost water and high-cost infrastructure often work against circular water management – and the economics of the true cost and value of water need to be better understood. Awareness of reusing water needs to be present among all parties, from those in business to decision-makers and other stakeholders. Information and data are also important in this respect. Dialogue promotes awareness and lack of it impedes collaborative action when a number of stakeholders are involved.

The perspectives, influence and impact of women in the response of business and industry to climate change are potentially very significant. It has been noted that women have a more comprehensive approach to mitigation and support broader actions regarding climate change. The dominance of men in energy, transportation and industry results in a more technological focus than a behavioural one (OECD, 2008). If women had a greater role in decision-making, holistic mitigation solutions could have more weight. In OECD countries, women are more likely than men to look at the environmental practices of the companies whose products they buy (OECD, 2008).

Case studies and surveys from UNGC/UNEP (2012) and WBCSD (2017) have identified some general features relating to companies and adaptation to climate change that have met with success when applied to water. Several relate to internal personnel efforts such as providing senior-level support, establishing teams to focus on climate change, and rewarding innovation and the realization of set goals. Others address company direction, for instance by linking adaptation to core business and company initiatives. This could include planning and designing for wastewater treatment early in a project, to ensure that wastewater is recognized as a value and a saving rather than a cost. Also significant is including the community interests in a participatory way and not simply as corporate philanthropy. Basin governance includes consideration for all users, including industry. This hinges on effective communication and good relationships, which are also important within a business. Businesses face a broad set of issues related to climate change. As water is very important in this regard, it must be part of an overall strategy and action plan.

Regarding corporate behaviour, water stewardship for companies is the next stage beyond water management, in order to recognize the shared use and long-term sustainability of water in river basins (Newborne and Dalton, 2016). It goes 'beyond the factory fence' and beyond conventional corporate social responsibility, addressing water withdrawal and allocation as more important issues than simple replenishment, which tends to preserve the business status quo. This may require compromises, trade-offs or water use reductions in water-stressed areas. Water stewardship efforts are tied to integrated water resources management (IWRM), which is often led by governments, as these need to foster room for dialogue with the private sector. Moreover, a human rights focus should be integrated into water stewardship and IWRM, taking a lead from the UN *Guiding Principles on Business and Human Rights* (HRC, 2011), to influence the direction of companies in these areas.

Figure 7.6 Climate adaptation and corporate strategy



Business environment increasingly volatile	How to do business in a changing climate	Business environment increasingly resilient
OPERATIONS		
Higher resources costs Productivity losses Physical damage, excessive losses	Resources, materials Labour force Fixed assets, infrastructure	Sustainable resources Stable labour pools Resilient structures, accessible insurance
MARKET STRATEGY		
Supply chain disruption Obsolete products	Supply chain, distribution Products, services customers	New logistic models New markets, emerging demand
STAKEHOLDER ENGAGEMENT		
Inefficiency Suspicion Conflict	Policy-maker Investors Communities	Partnerships Transparency License to operate

Source Adapted from UNGC/UNEP/Oxfam/WRI (2011, fig. 4, p. 28).

7.4 Moving forward

"*Delivering a water secure future will require a complete transformation of our global economy*" (CDP 2018, p. 11). Success will require companies to realign their business models, products and practices in ways that decouple production and consumption from the depletion of water resources. Responding to the global water and climate crises not only means better water management but, importantly, also better business management.

The way forward in managing water to mitigate and adapt to climate change points to some significant changes and large moves away from business-as-usual (Figure 7.6). "*Proactive companies can develop strategies to address climate change risks in their operations and supply chains, as well as strategies to capture new market opportunities and engage customers and communities to meet needs amid changing climate conditions*" (UNGC/UNEP/Oxfam/WRI, 2011, p. 28). One of the largest shifts will be seeing climate change as an opportunity. This will require an understanding of how adaptation can improve business prospects and why it is not just another unwanted costs, as well as recognition that climate change mitigation and adaptation are everyone's responsibility, and that energy and industry have important roles to play through many players. Owners, shareholders, employees, customers, suppliers and communities are in this together and will be affected both communally and personally. This will require a long-term approach with pre-emptive planning and actions both inside and outside the fence (UNGC/UNEP/Oxfam/WRI, 2011). Business will need to move away from the 'quarterly capitalism'[20] mindset (Barton, 2011). This is already evident with the idea of inclusive capitalism.[21] "*It is much smarter to anticipate and address climate change impacts and build resilience up front than to simply respond to the human and economic costs after impacts occur*" (UNGC/UNEP/Oxfam/WRI, 2011, p. 16).

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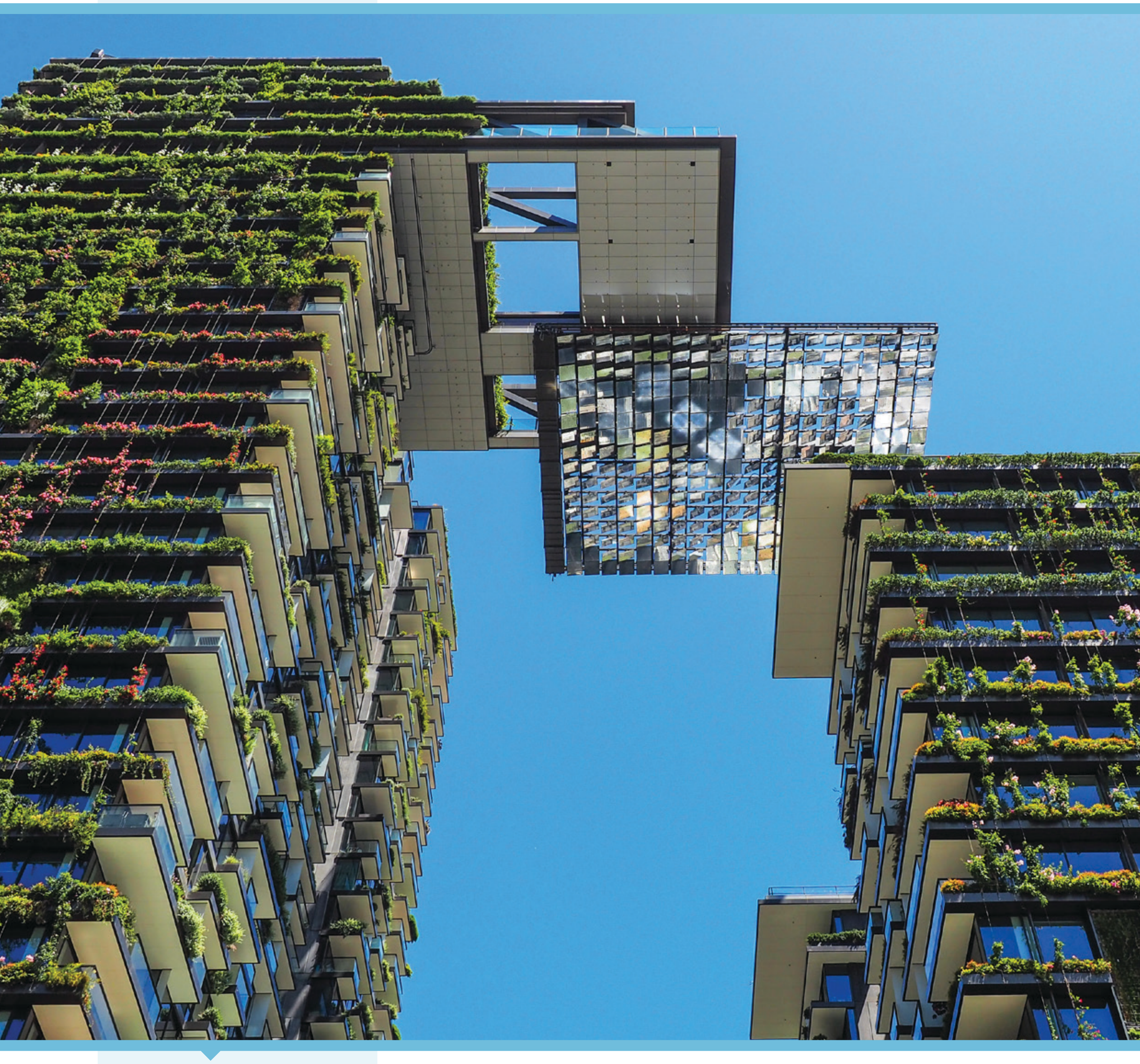
[20] This is a focus on quarterly (short-term) earnings targets, as opposed to long-term thinking and investment.

[21] 'Inclusive capitalism' is a global movement to engage leaders across business, government and civil sectors and encourage them to practice and invest in ways that extend the opportunities and benefits of our economic system to everyone." (Coalition for Inclusive Capitalism, n.d.).

8

Human settlements



Green skyscraper building in Sydney (Australia).

UN-Habitat | Graham Alabaster

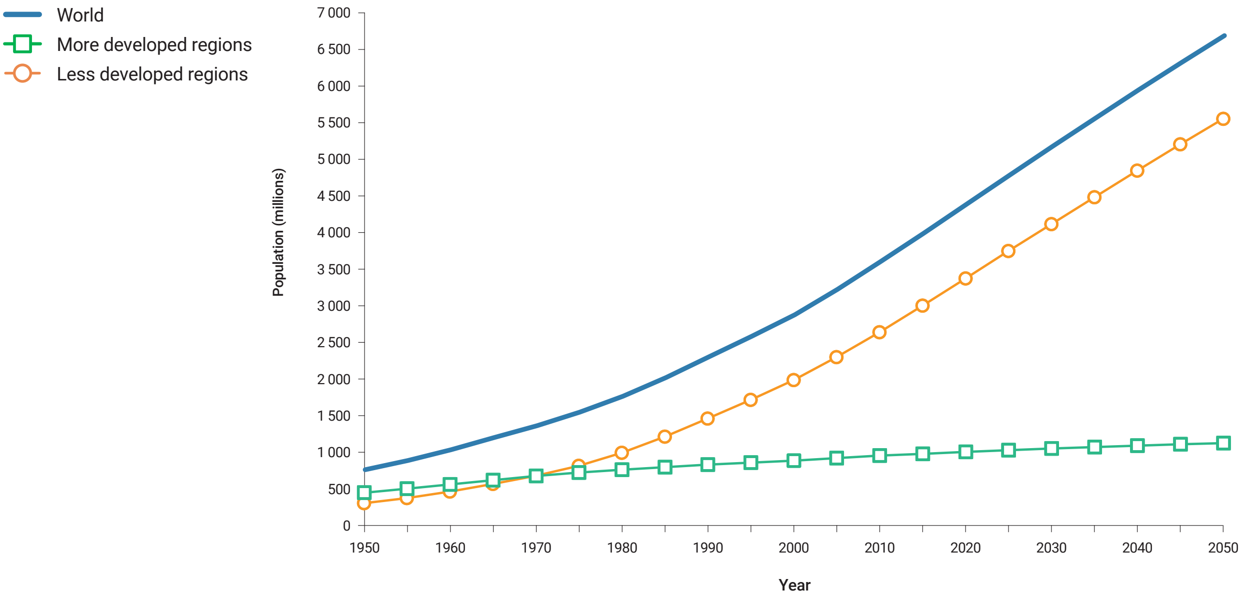
With contributions from: Nidhi Nagabhatla (UNU-INWEH)

This chapter describes the links between water, climate and human settlements, highlighting the need for increased resilience through flexible, long-term urban planning.

8.1 Introduction

A majority of the world's population (4.2 billion out of 7.6 billion in 2018) lives in cities. Projections of human settlements in the future (with a world population of 8.6 billion in 2030 and 9.8 billion in 2050) show that up to 60% of the world's population will live in cities by 2030, and 66.4% in 2050 (Figure 8.1). In 2018, three times as many urban dwellers were estimated to live in the less developed regions than in the more developed ones (3.2 billion versus 1.0 billion), and this ratio is expected to rise as the vast majority of urban population growth is expected to occur within the world's least developed regions (UNDESA, 2019).

Figure 8.1 Estimated and projected urban populations of the world, the more developed regions and the less developed regions, 1950–2050



Source: UNDESA (2019, fig. I.1, p. 13). © 2019 United Nations. Reprinted with the permission of the United Nations.

As human settlements continue to expand, pressure upon scarce resources, like water, is building up and further exacerbated by climate change impacts. Although cities are a hub for economic development, income generation and innovation, they are punctuated by inequities in health, water, sanitation and economic opportunities. For instance, haphazard and unsustainable urbanization has saturated water-provisioning service and infrastructure as well as existing wastewater treatment facilities, often time exposing people to health risks related to water quality and availability.

It is important to realize that the threats to water scarcity will be felt most keenly in the short term due to rapid urbanization, while the impacts of climate change will unfold over a longer time horizon. No explicit climate change signal has been detected in flood disasters in the historical records up to 2010. Population growth and economic development were the dominant drivers of increases in the numbers of people affected and economic losses suffered due to coastal and river floods (PBL Netherlands Environmental Assessment Agency, 2014).

8.2 Water, climate and urban development

Urban settlements are where the impacts of climate change on water systems are most keenly felt. These impacts include extremes in climate change from higher temperatures, reduced precipitation and drought on the one hand, and increasing heavy precipitation and flooding events on the other. It is precisely these extremes that make the planning of urban space and provision of infrastructure so difficult.

Haphazard and unsustainable urbanization has saturated water-provisioning service and infrastructure as well as existing wastewater treatment facilities

Reduced water availability will mean that by 2050 3.9 billion people (over 40% of the world's population) are projected to live under severe water stress (PBL Netherlands Environmental Assessment Agency, 2014). Climate change affects all parts of the water cycle. The areas of the world most affected in term of changes in water availability will include the Middle East, East Asia and much of Africa (IPCC, 2014a). The physical impact of flooding and resulting landslides will significantly affect urban settings, not just in damage to infrastructure but also loss of life and irreversible land destruction (see Chapter 4). Even in the developed world there is little resilience. In the United Kingdom, costs of flooding during the winter of 2015–2016 reached US$7.5 billion (Miller and Hutchins, 2017). About 50% of Asia's population (2.4 billion people) reside in low-lying coastal areas. The rising sea level will intensify the flood-related impacts of extreme climate events. Additionally, some agricultural land will be rendered unsuitable for use as a result of increased salination. In the Asia-Pacific region, storms, floods and landslides kill 43,000 people annually (UNESCAP, 2018).

The physical infrastructure for delivery of water and sanitation facilities can also be disrupted, leading to contaminated water supplies, and discharge of untreated wastewater and stormwater into living environments. Access to safe water is affected, with significant loss of life. Aside from waterborne diseases, many other health risks are exacerbated. Vector-borne diseases such as malaria, rift valley fever, and leptospirosis and others are often observed after flooding events (Okaka and Odhiambo, 2018). Groundwater sources are also significantly affected by flooding.

Although statistics indicate that water supply and sanitation coverage levels in urban areas are often higher than in rural areas, there are significant challenges associated with services provisioning (WHO/UNICEF, 2017). Most importantly, their environmental and financial sustainability is critical as countries strive to achieve the Sustainable Development Goals (SDGs). Urbanization patterns in a number of cities have become increasingly complex due to conflict-related migration, meaning that even the best planned service provision systems can be thrown into disarray by a rapid influx of people. Aside from the delivery of water and sanitation, other basic services, such as telecommunications and transportation, are also significantly affected.

8.3 The increased need for urban water resilience

Close to 70% of the world's population will live in urban agglomerations by 2050. The size, density and number of urban centres have increased considerably in the last few decades. By 2030, the world is projected to have 43 megacities with more than ten million inhabitants, the majority of which will be in developing regions. However, the fastest-growing urban agglomerations will be cities with less than one million inhabitants (many are located in Africa and Asia). Although about one in eight people lived in the 33 megacities worldwide in 2018, about 50% of the world's urban dwellers reside in settlements with fewer than 500,000 inhabitants (UNDESA, 2019). Many of these cities are vulnerable to the impacts of climate change. For example, the Indonesian capital city of Jakarta – with a population of 10.6 million in 2018

(UNDESA, 2018) – lies next to a large bay and sits on subsiding lands and floodplains, making it extremely vulnerable to floods and extreme climate events. Events that hamper access to clean water and extreme water situations are becoming increasingly frequent, an alarming call for the state to strengthen efforts for managing the resultant human migration. For example, flooding in 2007 forced 340,000 to 590,000 residents of Jakarta to migrate (Lyons, 2015).

The body of scientific evidence now categorically shows how climate change, particularly changes in precipitation and extremes in temperature, has exacerbated water management challenges (IPCC, 2014a). Many cities have experienced problems with water resources, as well as extreme flooding events. Without a more systematic approach to water management in cities, the actions planned in the past will rapidly become insufficient. The destruction of resources, reduced services and the commensurate impacts on health and the environment will be the result.

Key to a more effective approach is the understanding of urban development in the wider sense. Many of the factors influencing urban development are not currently well understood by the water community. Given that a combination of these factors exerts a huge influence, against a background of uncertainty, planning for different future scenarios will be necessary, rather than adopting a fixed and rigid approach. Through better engagement of the various stakeholders in cities, it should be ensured that they understand the different scenarios, so that difficult choices can be made and justified.

Urban water resilience goes way beyond the traditional city boundaries, including the potential reliance on distant watersheds. In some cases, several cities or a group of urban agglomerations will draw from the same aquifer, or there may be transboundary exchanges. In such cases, national, regional or international water resources issues can come into play.

8.4 Critical areas for action

8.4.1 Planning for the future

If cities are to adapt to climate change and survive, they will need to diversify their planning, going beyond a linear approach focused on service provision alone, while minimizing costs. This will necessitate a much broader assessment of water resources and a resilient system designed to protect against shocks. Such shocks may not only be caused by climate change, but can also be affected – for better or for worse – by multiple other factors, including:

- Population growth and urbanization (including climate- and conflict-induced migration);
- Technological advances;
- Economic growth;
- Land use planning; and
- Managing competition between sectors.

There are some examples where action in a related sector can indirectly impact water resources. For example, housing regulations can influence runoff from residential areas and thus help mitigate against flood risks. Planning for multiple scenarios is therefore a much better strategy, but it must be undertaken in an open and inclusive manner.

Effective consensus-building cannot be bypassed. Multi-stakeholder frameworks, institutionalized at the city level, are an effective way to support decision-making, particularly when faced with several different scenarios for the future. The recent drought in Cape Town, South Africa, clearly underscores the importance of a committed 'whole city' strategy (Box 8.1). Having the city authority as the enabler provides a reference point to which other stakeholders can peg their own commitments and promotes the idea of responsibility and ownership.

There is no prescriptive solution to address urban water resilience. Each situation varies and requires an independent analysis.

Box 8.1 Cape Town's post-drought collaborative water strategy

The water crisis in Cape Town, South Africa, was brought upon by a regional shortage in the Western Cape. Reservoir levels had been reducing since 2015, and between mid-2017 and mid-2018 the water levels were between 15 and 30% of their total capacity (CSAG, n.d.).

The crisis led to the development of a long-term strategy to protect resources, using a holistic approach. The strategy sets out the commitments of the metropolitan municipality of Cape Town and its citizens. Collaborative relationships are based on trust, and trust is built where there is transparency and mutual accountability, and where stated intentions of all partners are consistently translated into actions. The strategy is based on the following principles:

1. **Safe access to water and sanitation**. The City of Cape Town metropolitan municipality will work hard to provide and facilitate safe access to water and sanitation for all its residents in terms of well-defined minimum standards. In particular, the City will work with communities in informal settlements and with other stakeholders to improve the daily experience of access to water and sanitation, with an emphasis on building trust and increasing safety within these communities.
2. **Wise use**. Cape Town will promote the wise use of water by all users. This will include: a) pricing water based on the cost of providing additional supply, while retaining the commitment to provide a basic amount of water for free for those not able to afford paying for it; b) revising by-laws and planning requirements, and using other incentives to support water efficiency and the treatment and reuse of wastewater; c) supporting active citizenship by substantially improving customer management and engagement; and d) managing the water network effectively to reduce losses and non-revenue water.
3. **Sufficient, reliable water from diverse sources**. Cape Town will develop new and diverse supplies of water (which could include groundwater, and reused and desalinated water) in a cost-effective and timely manner to increase resilience and substantially reduce the likelihood of severe water restrictions in the future. It is committed to increasing the available supply by approximately 300 million litres per day over the next ten years, and in suitable increments thereafter, in a way that is adaptable and robust to changes in circumstances.
4. **Shared benefits from regional water resources**. Cape Town will work with key stakeholders and partners, including other urban and agriculture water users, and other spheres of government, to make the most of the opportunities to optimize the economic, social and ecological benefits of regional water resources, and to reduce the risks. This will be done through collaborative processes.
5. **A water-sensitive city**. Cape Town will actively facilitate its transformation over time into a water-sensitive city that makes optimal use of stormwater and urban waterways for the purposes of flood control, aquifer recharge, water reuse and recreation, based on sound ecological principles. This will be done through new incentives and regulatory mechanisms, as well as through investments in new infrastructure.

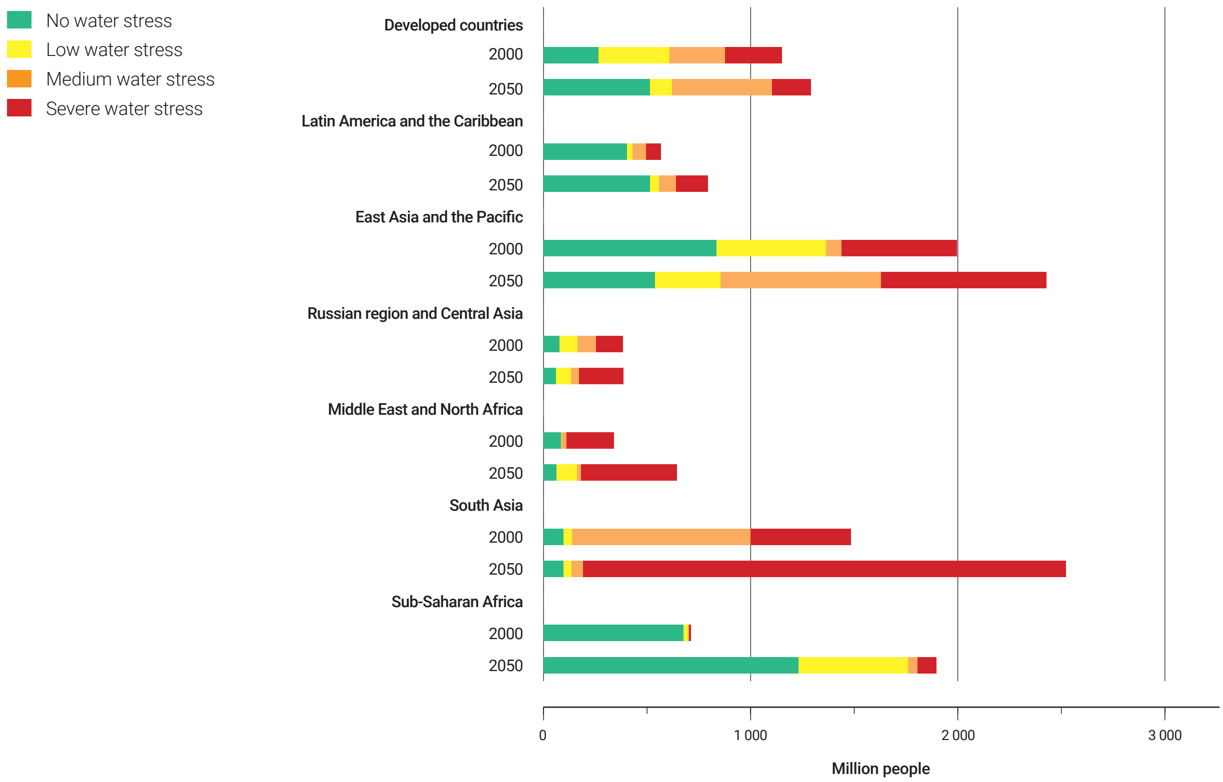
Source: City of Cape Town (2019).

8.4.2 Identifying critical areas of water scarcity

While climate change is already significantly impacting water resources, the demands of increased population and urbanization will further exacerbate water stress (defined here as a water exploitation rate of more than 40%) in many basins across the world, particularly those in densely populated areas in developing economies. By 2050, 40% of the world's population is projected to live under severe water stress (Figure 8.2), including almost the entire population of the Middle East and South Asia, and significant parts of China and North Africa. Globally, the rate of groundwater depletion has doubled between 1960 and 2000, equalling 280 km^3 per year in 2000 (PBL Netherlands Environmental Assessment Agency, 2014). Without good management strategies, these factors will entail huge risks to life (OECD, 2012).

Scarcity can be due to source limitation and/or increasing demand, as well as failure to invest in a diversity of sources, but also to institutional and management challenges. Limited capacity of local authority service providers results in high levels of 'unaccounted for' water, which in turn reduces revenue collection, resulting in a lack of resources for operations and maintenance. This vicious circle is a reality in many smaller utilities in Sub-Saharan Africa.

Figure 8.2 Number of people living under water stress under the Baseline Scenario*



Note: *The 'Baseline Scenario' stems from the third *Environmental Outlook* published by the Organisation for Economic Co-operation and Development (OECD, 2012). It assumes that no new policies are introduced and provides a benchmark against which the different policy variants are assessed.

Source: PBL Netherlands Environmental Assessment Agency (2014, fig. 2.6, p. 21). Attribution 3.0 Unported (CC BY 3.0).

Scarcity is often perceived due to competition for resources. In small urban and rural settlements, use of water for agriculture and in some cases industrial applications results in reduced availability for domestic uses. Scarcity in one sector is sometimes best addressed by actions in another sector. Improved irrigation practices, or industrial process optimization can free up water for domestic users. A key issue in this respect is that domestic supplies must be prioritized under the human rights to water and sanitation.

The example of Cape Town, presented in Box 8.1 shows how a climate-induced shortage was dealt with by adopting a new management approach.

8.4.3 Accounting for urbanization footprints on water resources

In many settings, urbanization can damage the ecosystems that provide the water and other natural resources necessary for sustainable growth. As a city grows and expands, pressure on the local ecosystems can increase to the point where, to survive, the city needs to look further afield, increasing its footprint. In practice, this can mean exploiting catchments that are distant or yet to be developed. A good example is the city of Dakar, where the city draws on the Lac de Guiers, which is approximately 250 km away. The authorities responsible for water supply are not always the ones that are responsible for catchment management. The mainly rural communities who survive on fishing and subsistence farming around the Lac de Guiers have a potentially larger impact on the water resource than the city dwellers in Dakar. Interventions to secure the water supply for Dakar are therefore directly related to the livelihood activities of distant riparian communities (Cogels et al., 2001). In this kind of cases, payment for environmental services schemes can be beneficial for both the urban population and the communities who live around the source (WWAP/UN-Water, 2018).

On the other hand, discharge of wastewater can also significantly impact downstream users. The Accra-Tema conurbation in Ghana draws water from the Densu River. Due to activities upstream, particularly sand mining, car-washing and wastewater treatment plant effluent discharges, the water quality in the river is so poor that it is close to the limits of economic treatment as a drinking water source (Yeleliere et al., 2018).

Rapid urban expansion frequently results in land of marginal quality being used for building houses and infrastructure. This may occur in wetlands, swamps and floodplains at the boundaries of a city. Destruction of such natural systems can have a significant impact on water storage and buffering capacity during periods of extreme precipitation or drought.

Consequently, those planning for improved urban water resilience need to look well beyond the boundaries of a city and consider the long-term impacts of urban expansion on water security. This will necessitate a wider consultation to include the ecological knowledge that is often locally available, based on or gained though decades of observation and good practice.

8.4.4 Innovative ways for local authorities and utilities to embrace resilience

Water and wastewater utilities can drive and lead change if they move from a business-as-usual approach focusing on service delivery at the lowest cost to a forward-looking strategic plan. Such plans must cover both short-term solutions and long-term actions to promote efficient delivery of services whilst addressing emergency preparedness and long-term capital investment.

Short-term solutions can include demand management, one of the most cost-effective tools to mitigate against scarcity. Water demand management effectively combines leakage reductions with the promotion of a water-saving culture and other commercial and institutional instruments. As a result, additional investments to develop new water resources supply projects are less urgently needed, so that money is saved in the longer term. In a situation where system losses are high, this should be a prerequisite for any future water resource supply projects. The water scarcity situation in São Paulo, Brazil is a clear case in point (Box 8.2).

Box 8.2 Analysis of the water shortage in São Paulo, Brazil

In 2015, the water distribution system of the Metropolitian Region of São Paulo (MRSP) was at the brink of collapse. Homes that were supplied exclusively by the Cantareira reservoir were especially vulnerable. According to data of the Companhia de Saneamento Básico do Estado de São Paulo S.A (Basic Sanitation Company of São Paulo State – SABESP), on 23 April 2015 the six main river springs that supply the MRSP contained 305 billion litres of water, while the same sources had amounted to 558 billion litres at the same time of the year in 2014. This means that even with above-average rainfall in January and February, the situation was critical. While in 2014 there still was a serviceable volume in the Cantareira system, in 2015 the city had to rely on the technical reserve.

A water crisis like this can become an opportunity to achieve more efficient and sustainable water consumption, avoid losses and pollution, and promote citizen involvement. For this to occur, the suggested measures and projected scenarios must be clear enough to obtain the trust and support of citizens, through information about the ‘real’ extent of the crisis and the measures to be taken.

It is important to analyse the issue from the perspective of opportunities, as the crisis has demonstrated a catalysing potential for structural advances the country needed. The crisis enabled a channel for the definition of major structural works for the states of São Paulo and Rio de Janeiro, to be sponsored mostly by funds from the Federal Government. The water crisis also sped up deep discussions about polemic issues like the transposition of rivers (the drought in northeastern Brazil had lasted for at least three years), the high losses in the supply network (estimated around 37%), conflicts of interest in the concession model for private or mixed-capital companies, political interference on technical issues, government negligence, the need for alternative sources of water (such as reclaimed water, rainwater, groundwater and even desalination technologies), evaluation of individual and collective behaviour towards sustainability, and the need for improvement in the institutional and social communication model.

Source: Soriano et al. (2016).

> *Those planning for improved urban water resilience need to look well beyond the boundaries of a city and consider the long-term impacts of urban expansion on water security*

Getting locked into long-term expensive, inappropriate capital-intensive investments can greatly constrain future responses, reduce resilience and render cities extremely vulnerable. The uncertainty related to future scenarios means that every effort should be made to adopt flexible approaches, focusing on low-regret, short-term actions. The same applies to capacity-building. From the experience of São Paulo, it becomes clear that the element of trust between the authorities and citizens is also very important.

In summary, in many countries and cities, the development of strategic frameworks is desperately needed. Who in government is responsible, and which actions are necessary, is difficult to assess and depends on the existing structures. It is very likely, given the integrated nature of needed actions, that the responsibility should rest with a national planning ministry or agency.

8.5 Conclusions and recommendations

1. Understanding the wider issues related to sustainable urban development are critical if we are to fully understand the direct and indirect impacts of urban water management on climate resilience. The impacts of urbanizing communities on local ecosystems both close-by and distant, including the critically important wetlands, also need careful consideration (Fitzgerald, 2018).

2. Future planning for the various scenarios to support urban water and climate resilience is necessary to ensure the right combination of short-term, low-regret interventions. Longer-term large-scale investment plans can address the real concerns facing cities and urban agglomerations. There is a wide range of technological, engineering and nature-based solutions (NBS) to ensure urban resilience. The best solutions to adopt are, however, context-specific.

3. It is important for city-level actors, and in particular local authorities and utilities, to lead and guide other stakeholders in a unified approach, making the best use of multi-stakeholder consultations and ensuring that campaigns and advocacy are successful. It is critical to emphasize consultations with all stakeholders, particularly the people most affected by climate change, water scarcity and discrimination.

4. A full analysis of future scenarios can be enabled by a greater understanding of the ecological conditions upstream and downstream, in the areas where water is abstracted and wastewater discharged. In cases of inter-basin transfers, a full analysis of impacts is necessary, including the participation of communities, citizens or city managers to ensure the longer-term viability of such schemes.

9

Water–Climate–Energy–Food–Environment Nexus

Equipment for a solar-based irrigation project.

WWAP | Richard Connor, Jos Timmerman, Stefan Uhlenbrook and Engin Koncagül

With contributions from: John Payne (UNIDO); Christophe Cudennec (IAHS); Lucia de Strasser (UNECE); and Tamara Avellán (UNU-FLORES)

Building on the information and analyses provided in Chapters 3 through 8, this chapter expands on the interlinkages between the main water use sectors, describing how decisions made by one can have significant repercussions on the others. It highlights the need for a consolidated approach to addressing climate change through water in order to maximize co-benefits and address trade-offs.

9.1 Accounting for interlinkages

The previous chapters of this report have focused on what can be done to adapt to and mitigate climate change through improved water management across different water use sectors and stakeholders. Addressing climate change through water management should build on a coordinated response that strikes a balance between different sectoral objectives and the needs of all water users, including the environment. However, different sectors and stakeholders can face a variety of challenges with respect to both water management and climate change adaptation and mitigation. The often strong interlinkages between these groups can, in some cases, lead to synergies and cross-benefits, and in other cases require trade-offs. The scope and magnitude of opportunities and trade-offs will also vary based on the particular disciplinary knowledge, capacity, needs and objectives of the different groups. Analyses across sectors and boundaries are therefore important in order to maximize overall benefits. Furthermore, while the nexus approach is theoretically symmetrical, it still needs to be approached through different water and climate change perspectives in order to better understand the linkages and bridge the knowledge gaps across different disciplines (Lui et al., 2017).

Addressing climate change through water management should build on a coordinated response that strikes a balance between different sectoral objectives and the needs of all water users, including the environment

9.1.1 The energy perspective

Water use requires energy. In 2014, the abstraction, distribution and treatment of water and wastewater accounted for an estimated 4% of global electricity consumption, along with 50M t.o.e.[22] of thermal energy[23] (mainly diesel used for irrigation pumps and gas in desalination plants) – and the amount of electricity used in the water sector has been projected to almost double by 2040 (see Figure 3.2). The energy requirements for irrigation and drinking water further increase when the water has to be brought from greater distances or from deeper groundwater bodies, or as the source quality decreases. The largest predicted growth in electricity consumption is for desalination as well as wastewater treatment (IEA, 2016), although the latter can be an energy-positive process (sludge to energy) and modern technology should rather lead to a decrease of energy use in the coming years (see Section 9.1.4). Therefore, any reduction in water use, through greater water savings (i.e. demand management) or improved water use and processing efficiency (e.g. leak reduction) has the potential to reduce the energy demand from the water sector and thus help mitigate climate change, if said energy source is from fossil fuels.

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[22] Tonnes of oil equivalent.

[23] Energy consumption by the water sector [in 2014] is roughly equal to all energy used by Australia (IEA, 2016).

Conversely, energy production also requires water. Although this is probably most evident for growing biofuels or for mining fossil fuels (e.g. hydraulic fracturing, or 'fracking'), cooling processes in thermal power generation actually account for the largest energy sector water use in terms of withdrawals (see Section 7.3.1). Whereas cooling can affect water availability through evaporative losses, hydropower reservoirs can also 'consume' large amounts of water through evaporation (Hogeboom et al., 2018). Dams and artificial reservoirs also alter hydrological systems, which can in turn impact on the functioning of ecosystems and their services, further affecting the availability and quality of water. Irrigation for biofuel production (Box 9.1) not only consumes water, but can also impact water quality through runoff of sediments, nutrients and agrochemicals, making it less suitable for other uses. With their very low water requirements, renewables such as wind, solar photovoltaic (PV) and certain types of geothermal power generation are by far the best energy alternatives from a water demand perspective (WWAP, 2014).

9.1.2 The food and agriculture perspective

Water efficiency measures in agriculture can increase water availability and reduce the energy needed for pumping, in turn further reducing the water needed for energy production. Such lower energy demand can also lead to a reduction in greenhouse gas (GHG) emissions, thus mitigating climate change. In this way, cross-benefits can lead to positive reinforcements. Similarly, increased use of renewable energy in agriculture (e.g. solar PV pumps), as well as greater energy efficiency also provide additional opportunities to lower GHG emissions and to support the livelihoods of smallholders (see Box 6.4).

Box 9.1 Biofuels

Biofuel production has been estimated to use about 2–3% of all water and agricultural land globally (Rulli et al., 2016). Biofuels also account for 7% of all energy-related water withdrawals (more than oil and gas in primary energy production), including significant amounts for steam in fermentation (IEA, 2016). The water requirements for biofuels depend on whether crops are irrigated or rainfed (IEA, 2016). If irrigated, there are different requirements depending on the region and the crop grown – sugarcane, corn and soybean being the most water-demanding – and the efficiency of the irrigation systems.

Second-generation biofuels, manufactured from various types of non-food biomass, offer some promise in terms of lowering the amount of water used. At present, they mainly include agricultural, food and municipal waste, with water being used for the original purpose of the crop. However, when dedicated crops are grown for advanced biofuels, the water use figures would rise.

In theory, biofuels can mitigate greenhouse gas (GHG) emissions in relation to fossil fuels because the CO_2 they emit when combusted is balanced by the CO_2 they capture while growing (Biofuel, n.d.a). However, they are not carbon-neutral because of the energy that is required to grow and process the crop, including clearing the land, cultivating the ground, planting and irrigation. If this is added to the GHG emissions from biofuel combustion and distribution to the customer, the result is a net addition to CO_2 emissions (Biofuel, n.d.a; n.d.b). This is further compounded by land use changes, because more CO_2 is released when native land is cleared and drained, and the CO_2 uptake by the original plants is lost. Since original forest is usually more efficient at capturing and storing CO_2 than biofuel crops, deforesting native land can actually produce a carbon 'debt' that may take hundreds of years to reverse (Biofuel, n.d.b). While the most conventional biotechnology has been reported to produce less than a 40% reduction in GHG emissions compared to fossil fuels (Doornbosch and Steenblik, 2007), other life cycle analyses suggest that such metrics come with a high degree of uncertainty (Hanaki and Portugal-Pereira, 2018).

The Intergovernmental Panel on Climate Change (IPCC, 2012) pointed out that the growth in biofuel production is more problematic to project than the growth in other renewable energies, because of the many feedback mechanisms and potentially large regional differences, leading to significant uncertainties. For example, large-scale bioenergy production (without complementary measures) can result in negative effects with respect to deforestation, as well as higher CO_2 emissions from land use change, nitrogen losses and higher food prices (Humpenöder et al., 2018). While biofuels offer potential, the balance between their net water use and net GHG emissions needs to be considered, and decisions should be made for each case individually, based on local circumstances, to address broader trade-offs.

In reality, however, increased irrigation efficiency (e.g. drip irrigation) at farm scale has often not led to water savings at larger scales (FAO, 2017c; Koech and Langat, 2018) – rather, it is the crop production that has increased by using the same overall volumes of water. This reinforces the critical importance of conservation agriculture (see Chapter 6), which allows soils to retain more water (thus further reducing water and energy demand), organic matter (carbon) and nutrients (WWAP/UN-Water, 2018). In this way, conservation agriculture directly contributes to climate change mitigation and adaptation, with additional ecological benefits and sustainable food and fiber production.

Avoiding the loss and waste of food provides another path to reducing GHG emissions

Avoiding the loss and waste of food provides another path to reducing GHG emissions. An estimated 25–30% of total food produced is lost or wasted across all stages of the food supply chains (FAO, 2013b; IPCC, 2019c). As food waste decomposes, it releases GHGs. Between 2010 and 2016, global food loss and waste contributed 8–10% of total anthropogenic GHG emissions[24] (IPCC, 2019c), a ratio that could rise above 10% by 2050 (Hiç et al., 2016). Since agriculture accounts for 69% of global water withdrawals (AQUASTAT, 2014), reducing food waste could also have significant repercussions on water (and energy) demand, thus providing a means of adaptation (relieving water stress) and mitigation (through reduced energy use).

9.1.3 The land use and ecosystem perspective

The biomass and soils of properly managed forests, wetlands and grasslands provide mitigation opportunities through carbon sequestration (IPCC, 2019c), with significant additional benefits in terms of nutrient cycling and biodiversity. However, while healthy ecosystems have the potential to capture carbon at a rate which far exceeds many related human efforts, degraded ecosystems can turn from carbon sinks to carbon sources. Improved water management for maintaining and/or rehabilitating healthy ecosystems is critical in this respect, most notably in the case of wetlands, which accommodate the largest carbon stocks among terrestrial ecosystems (GIZ/adelphi/PIK, forthcoming). These ecosystems also provide high-value 'green infrastructure' for enhancing source water protection, playing important roles in regulating water flows and maintaining water quality. However, "*there is a high degree of variation in the impacts of ecosystems on hydrology both within and between ecosystem types or subtypes, their location and condition, climate and management … for example, trees can increase or decrease groundwater recharge according to tree type, density and location*" (WWAP/UN-Water, 2018, p. 27).

It is therefore imperative that the impacts of land use change, including re/afforestation in particular, on the local hydrological systems be taken fully into account. In July 2019, an article by Bastin et al., describing the enormous potential GHG mitigation effects of a massive afforestation effort (more than one trillion trees over 900 million hectares), received worldwide attention through various forms of media. Although the results were hotly debated,[25] neither the initial paper nor its adversaries provided any in-depth consideration of the water requirements and eventual hydrological impacts (or potential benefits, if any) of such a scheme. This further illustrates the general disconnect between the climate and water science communities.

As described in the Prologue, climate projections at different time and spatial scales may or may not translate to real trends on the ground, in large part due to the complexity of interconnections and feedback loops between water and land use at local and regional scales. Various hydrological processes (infiltration, soil water storage, recharge, plant water use, other water uses) add to this complexity, such that simplistic cause–effect chains are not necessarily applicable in many 'real-world' cases. For example, although General Circulation Models (GCMs) might predict an overall increase in precipitation over a year (or even a season), this may not translate to increased water availability, especially when the increased precipitation comes in the form of heavy rainfall events,

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[24] This estimate includes the GHG emissions related to the production of food, as well as from the decomposition process itself.

[25] See for example www.realclimate.org/index.php/archives/2019/07/can-planting-trees-save-our-climate/.

and may even result in more frequent and/or prolonged periods of drought – hence the importance of sustainable land use (Box 9.2). Indeed, "*the successful implementation of response options depends on consideration of local environmental and socio-economic conditions. Some options such as soil carbon management are potentially applicable across a broad range of land use types, whereas the efficacy of land management practices relating to organic soils, peatlands and wetlands, and those linked to freshwater resources, depends on specific agro-ecological conditions (high confidence)*" (IPCC, 2019c, p. 19).

9.1.4 The water supply, sanitation and wastewater treatment perspective

Beyond the energy savings related to more efficient water use mentioned above, improved approaches to the treatment of water, and especially wastewater, offer an even broader range of mitigation opportunities. For example, the reuse of untreated or partially treated wastewater can reduce the amount of energy associated with water extraction, advanced treatment and, in cases where the wastewater is reused at/or near the release site, transportation.

The reuse of untreated or partially treated wastewater can reduce the amount of energy associated with water extraction, advanced treatment and, in cases where the wastewater is reused at or near the release site, transportation

As described in Section 3.3, untreated wastewater is an important source of GHGs. With more than 80% of all wastewater globally released to the environment without treatment (WWAP/UN-Water, 2018), treating its organic matter prior to its release can reduce GHG emissions. The biogas produced from wastewater treatment processes can be recovered and used to power the treatment plant itself, rendering it energy-neutral and further enhancing energy savings. Advanced wastewater treatment systems also provide opportunities for the recovery of other raw materials, such as nutrients that can then be transformed into fertilizer and sold on the market, thus further increasing the return on investment by generating new revenue streams (WWAP, 2017), with additional benefits to human health and the environment.

However, wastewater treatment can itself lead to the release of certain types of GHGs. Nitrous oxide (N_2O), for example, is a potent[26] GHG emitted during wastewater treatment processes. Although these emissions are relatively small (3% of the estimated total anthropogenic N_2O emissions), they can account for an estimated 26% of the GHG footprint of the total 'water chain' (Kampschreur et al., 2009). N_2O emissions vary substantially between plants, due to different designs and operational conditions, as well as the concentrations of nitrogen-rich compounds (e.g. urine) contained in the wastewater itself. In general, plants that achieve high levels of nitrogen removal emit less N_2O, indicating that high water quality can be achieved in conjunction with lower N_2O emissions (Law et al., 2012). Increased understanding of the fundamental processes responsible for N_2O production in wastewater treatment systems should lead to improved plant design and operation. Furthermore, nitrogen recovery from wastewater does not negatively affect the recovery of phosphorus and cellulose, nor the production of biogas (Van der Hoek et al., 2018).

Constructed wetlands can be effective in treating wastewater (with little or no additional energy inputs), particularly in settings where low technology and low maintenance represent operational constraints, providing a relatively inexpensive source of water for irrigation. While the biomass harvested from constructed wetlands can be used as a renewable fuel source for second generation biofuels (Box 9.1) (Avellán and Gremillion, 2019), some evidence suggests that these systems act as net sources of atmospheric GHGs (Picek et al., 2007; Tao, 2015), although the opposite has also been reported (De Klein and Van der Werf, 2014).

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[26] N_2O has a Global Warming Potential 265–298 times that of CO_2 (US EPA, n.d.).

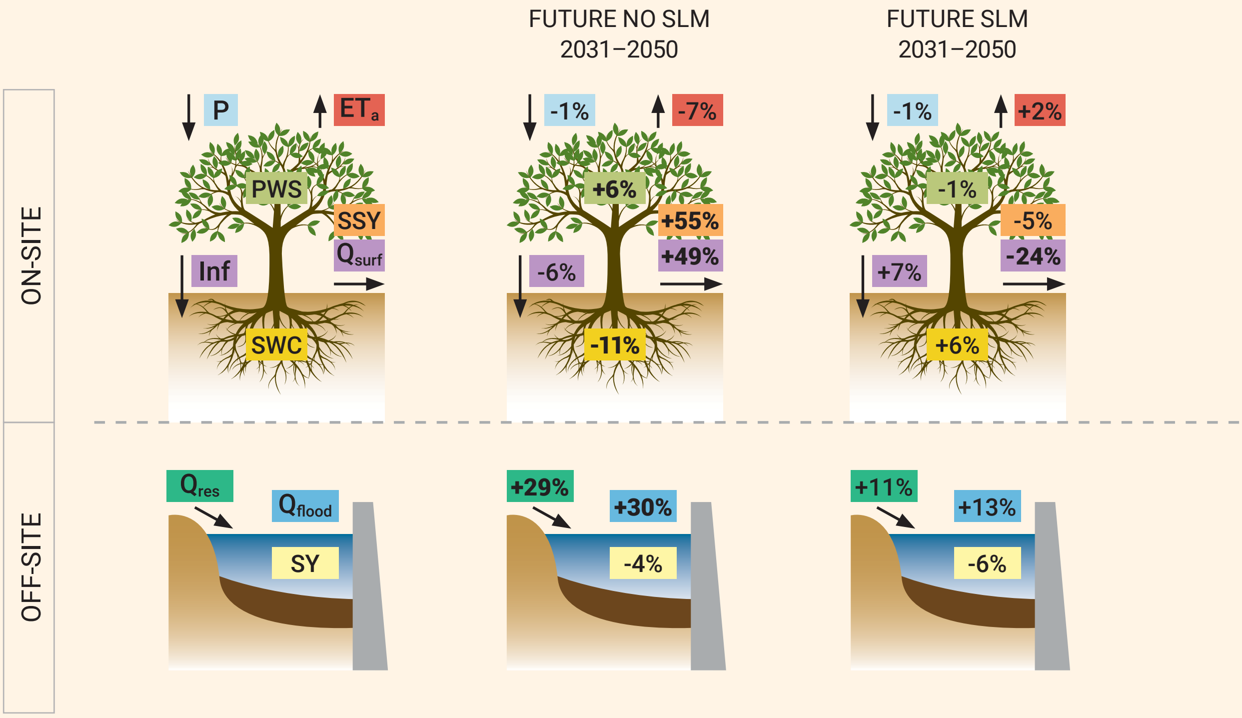
Box 9.2 How climate change and sustainable land management affect water availability

In the semi-arid Segura River catchment (Southeast Spain), climate change is expected to cause a decrease in total precipitation as well as, more importantly, an increase of extreme precipitation. A model-based study examined how increases in extreme rainfall affect the distribution between water stored in the soil (green water) and water stored in reservoirs (blue water). The results showed a redistribution of water within the catchment, with less green water, as a result of prolonged drought periods, but more blue water, as a result of increased extreme precipitation and decreased infiltration. Extreme rainfall also caused an increase of flood discharge and soil erosion, threatening water security in this catchment (Eekhout et al., 2018).

Sustainable land management (SLM) practices are increasingly promoted to contribute to climate change mitigation and adaptation. Eekhout and De Vente (2019) showed that the impacts of climate change are almost entirely reversed by large-scale implementation of SLM (see Figure). The evaluated SLM scenarios were defined in close collaboration with stakeholders, who identified reduced tillage and organic amendments as the most promising SLM practices in rainfed agriculture. SLM increases the water-holding capacity of the soil, leading to increased infiltration and reduced plant water stress. When extreme rainfall increases under climate change, the implementation of SLM mitigates this effect on rainfall by reducing surface runoff and related processes, such as flood discharge, soil erosion and reservoir sedimentation.

These results emphasize that projected changes in total precipitation alone are not enough to infer how water availability will change over time. Extreme events and land management practices have a significant impact on the distribution of water between the surface and the soil. These changes may affect the potential of rainfed in comparison to irrigated agriculture, which rely on different water sources. SLM may have a positive impact on soil water and on flood prevention, but also affect surface water and economic activities that rely on it.

Figure The on-site and off-site impacts of climate change and implementation of sustainable land management



Note: The left panel defines the indicators, where P is precipitation, ETa is actual evapotranspiration, PWS is plant water stress, Inf is infiltration, SSY is hillslope erosion, Qsurf is surface runoff, SWC is soil water content, Qres is reservoir inflow, SY is reservoir sediment yield and Qflood is flood discharge.

Source: Adapted from Eekhout and De Vente (2019, fig. 1).

Contributed by J. P. C. Eekhout and J. de Vente (Spanish National Research Council).

Wetlands in Khao Sam Roi Yot National Park (Thailand).

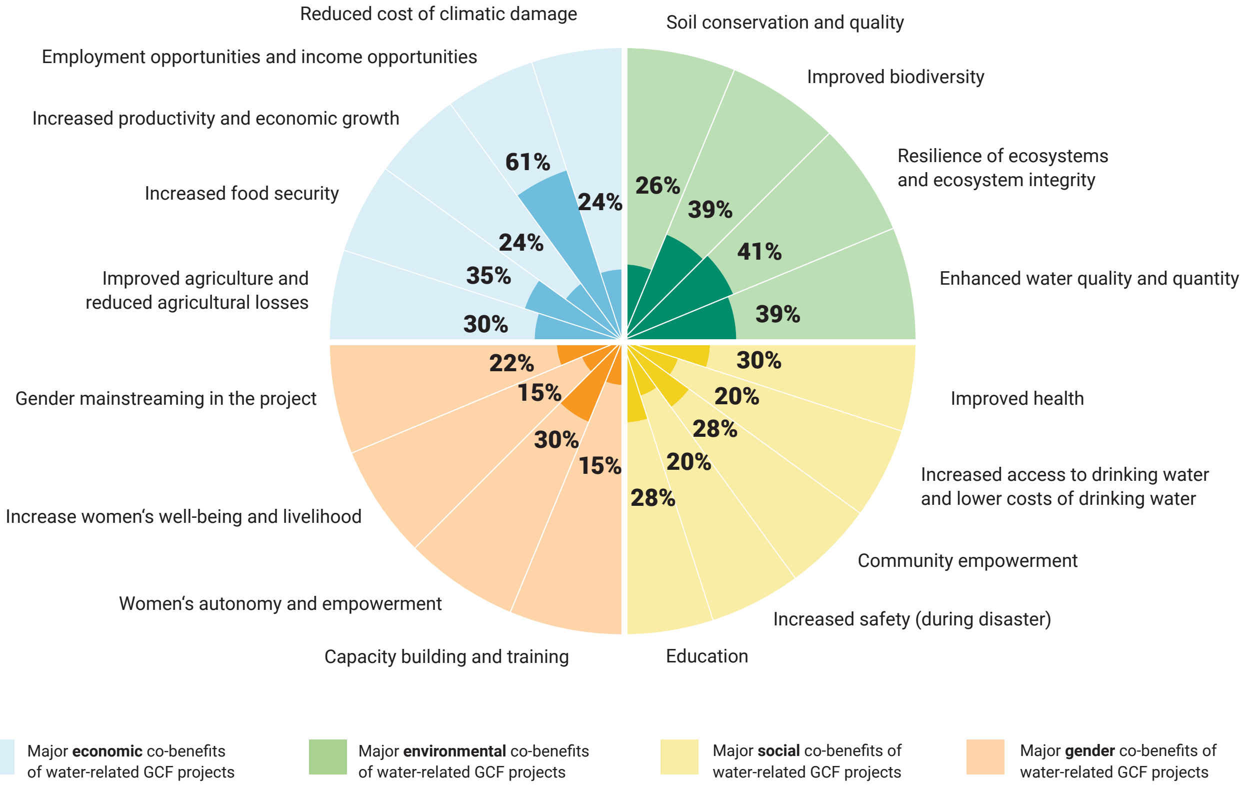
9.2 Co-benefits

Besides the water, climate, energy and agriculture nexus, linkages to other sectors and stakeholder groups are often strong. The 2030 Agenda for Sustainable Development explicitly recognizes that social, economic and environment systems are symbiotic. The United Nations (2018a) demonstrated that Sustainable Development Goal (SDG) 6 (the water goal) is interlinked to all other SDGs, and that water is often an enabler for making progress in achieving other SDGs, while in some cases trade-offs have to be realized (see Chapter 2). Conversely, progress towards SDG 6 also depends on progress in most of the other SDGs and, particularly, SDG 13 (climate action). Such interconnectedness is exemplified by the case of improving wastewater treatment, which not only directly serves the interests of SDGs 6 (both in terms of addressing the sanitation and water quality Targets 6.1 and 6.3) and 13 (as well as the Paris Agreement), but also other SDGs (see Figure 2.1). Human health and human settlements (see Chapters 5 and 8) are among the key areas through which water-related climate interventions can generate multiple co-benefits. This points to the importance of policy coherence and the appropriate timing and sequencing of policies, reforms and related investments, as described in Chapters 2, 11 and 12.

An analysis of the co-benefits of water-related projects under the Green Climate Fund (Tänzler and Kramer, 2019) revealed the extent to which they are embedded into the broader socio-economic context of the respective countries. While employment and income opportunities are identified as a co-benefit in more than half of the projects, a number of other co-benefits, ranging from education and capacity development/training to biodiversity and food security, are also regularly acknowledged (Figure 9.1). Yet many project proposals remain far too concentrated on the central objective and fail to fully describe the broader (and often very strong) development focus. Proposals for water-related projects that identify several specific (and realistic) co-benefits that can be attained, and that describe how these co-benefits will be measured, are more likely to obtain social, political and financial support (see Chapter 12).

In summary, adaptation and mitigation actions by one sector can directly influence water demand, which can in turn augment or reduce the local/regional water availability (including quality) for other sectors. In cases of reduced water demand, such actions can lead to multiple benefits across sectors and boundaries, whereas increased water demand can result in the need for trade-offs over the allocation of limited supplies.

Figure 9.1 Co-benefits of water-related projects in the Green Climate Fund portfolio



Note: GCF: Green Climate Fund.

Source: Tänzler and Kramer (2019).

10

Regional perspectives

Helicopter dropping a large load of water onto a bushfire in support of fire-fighting efforts by crews on the ground in Bundoora (Melbourne, Australia).

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ODI | Nathaniel Mason, Roger Calow, Leo Roberts, Adriana Quevedo and Merylyn Hedger
UNECA | Frank Rutabingwa
UNECE | Hanna Plotnykova, Sonja Koeppel, Francesca Bernardini and Sarah Tiefenauer-Linardon
UNECLAC | Marina Gil, Andrei Jouravlev, Shreya Kumra and Silvia Saravia
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This chapter describes how the nature and scale of water-related impacts of climate change go beyond national borders, as do the potential responses. Deeper insights into priority challenges and opportunities are drawn from country- and region-level examples, to demonstrate why and how opportunities for action arise in each region.

10.1 Overview

Adapting to impacts of climate change on water first and foremost deals with *how* water is *managed* – with what policies, institutions, management tools and resources. Water-related impacts of climate change ignore administrative borders between and within countries. Therefore, climate-smart water management has the greatest impact when developed and coordinated across national borders. Some responses, such as water-sharing arrangements that can adapt to changing flow regimes, necessitate a basin perspective, more often than not crossing national or subnational political and administrative borders. For others, such as the development of early warning systems that are able to deal with precipitation extremes, which are driving more intense and frequent floods or droughts (Chapter 4), there is need to look still further: to the subcontinental or even continental scale. This chapter takes a look at the implications of the regional and transboundary dimensions of the water–climate interface.

Regional perspectives are typically missing from global climate dialogue, agreements, funding mechanisms and action. To date, the majority of climate change policy and action is framed at the national level and driven by national governments: the negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) are led by and focused on sovereign states, as are many climate finance mechanisms (Chapter 12) and the majority of targets set under the 2030 Agenda, the Paris Agreement and the Sendai Framework for Disaster Risk Reduction. Building on the rationale presented in Chapter 2, this chapter presents water as *the* international 'climate connector' that will lead to new collaboration and coordination mechanisms, and help achieve the interlinked global agreements on development, climate change and disaster risk reduction (DRR) (UN-Water, 2019). It considers regional readiness to address these challenges, with reference both to countries' maturity in water resources management and their strategies for climate adaptation, taking nationally determined contributions (NDCs) as a proxy, and looking across countries covered by the Regional Commissions (RECs) of the United Nations (UN).[27] It also underscores the crucial role for international organizations operating at the transboundary basin or regional level. Over decades, water agencies have created such players, which can support coordinated and coherent climate mitigation and adaptation action at the water–climate interface.

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[27] These include the UN Economic Commission for Africa (UNECA); the UN Economic Commission for Europe (UNECE); the UN Economic Commission for Latin America and the Caribbean (UNECLAC); the UN Economic and Social Commission for Asia and the Pacific (UNESCAP); and the UN Economic and Social Commission for Western Asia (UNESCWA).

There are enormous differences within and between regions in terms of how the climate is changing and how these changes interact with water. The 2014 report of Working Group II for the Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC, 2014a) remains IPCC's latest region-by-region global assessment. It provides important context on the physical science, in terms of changes in heavy precipitation, dryness and drought at a subcontinental scale. These broad changes will themselves have regionally varying water-related impacts, including on runoff, evapotranspiration, flood risk and water quality, which are mediated by local factors including land use and hydrogeology. However, as described in the Prologue, there remains a high degree of uncertainty with respect to the future impacts of climate change on the hydrological cycle, particularly at the basin and sub-basin level. And little is known about the climate–water interface insofar as groundwater is concerned (Taylor, 2009; Gleeson et al., 2012).

To support countries, regional policy communities need to assess impacts, vulnerabilities and adaptation pathways within their geographical and decision-making contexts

To support countries, regional policy communities need to assess impacts, vulnerabilities and adaptation pathways within their geographical and decision-making contexts (IPCC, 2014a). A good example is the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR), established by UNESCWA together with ten other organizations. The Initiative has a strong emphasis on engaging and strengthening institutions for climate change assessment at the national as well as regional scale, and the RICCAR Arab Domain has been adopted as the Middle East and North Africa Domain of the Coordinated Regional Climate Downscaling Experiment (CORDEX) (UNESCWA et al., 2017).

10.2 Addressing water-related impacts of climate change across countries and regions

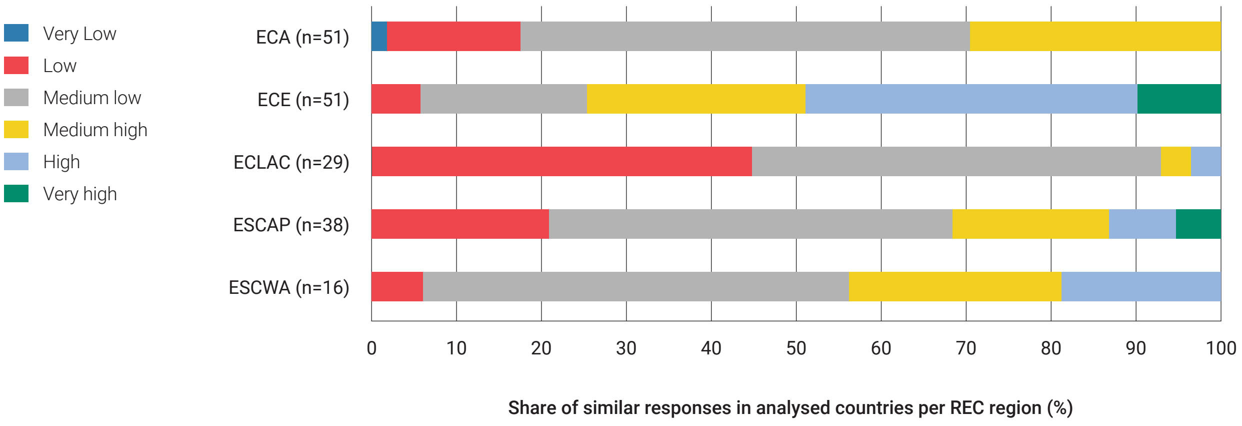
The water-related physical impacts of climate change are only one source of variation between and within regions. What also varies is adaptive capacity, including policies, plans and management capacities for addressing climate change impacts on water resources and water-dependent sectors.

10.2.1 Integrated and transboundary approaches

Addressing climate change via water requires taking *integrated approaches* – investing in better and more accessible information, stronger and more flexible institutions, and natural and built infrastructure to store, transport and treat water; taking action at all levels – local, national, river basin, and global; balancing and sequencing soft and hard investments; managing intersectoral and geographic trade-offs; avoiding maladaptive consequences; balancing equity, environmental and economic priorities; and harnessing both adaptation and mitigation benefits. The core components of a water resources management system that can respond to climate change are well known and include, for example, water-sharing arrangements based on robust water resource assessment and water accounting systems that can respond to climatic shifts and variability (GWP, 2019a). Over 15 years ago, Mauritania's National Adaptation Programme of Action (NAPA) already recognized integrated water resources management (IWRM) as one of the "*appropriate solutions to adaptation to climate change*", noting practices and actions such as "*regular assessment of availability of water resources and requirements*", "*monitoring and mitigation of impacts related to … sustainable development … respecting the conservation of the environment*", and "*management regulations to prevent conflict of use*" (Islamic Republic of Mauritania, 2004, pp. 26–27).

The 2030 Agenda recognized that IWRM practices would be needed to bring about *availability and sustainable management of water and sanitation for all*, as formulated under Sustainable Development Goal 6 (SDG 6). A particular indicator was set to monitor the management practices (6.5.1). Although a country's SDG 6.5.1 score does not specifically focus on whether its water resources management practices are adequate to address impacts of climate change, it does reflect its self-assessment of the maturity of its water management systems, particularly by taking *integrated* approaches. The first global SDG 6.5.1 progress report, released in 2018, not only revealed massive, persistent and growing gaps in achieving the water goal, it also highlighted countries' self-perceptions of rather limited maturity in managing water resources (UN Environment, 2018). In all UN REC regions, the majority of countries lack a solid foundation for IWRM (Figure 10.1). No countries in the ECA region report levels of implementation scored as 'high' or 'very high', and in ECLAC, only one did so. Under a fifth did so in ESCWA and ESCAP, and even in ECE, less than half claimed high or very high levels of implementation.[28]

Figure 10.1 IWRM implementation, by UN REC region



Source: Regional analysis of data on IWRM implementation from UN Environment (2018).

> *There is still significant room to increase commitments to climate change adaptation, and to the reduction of climate-related disasters, in transboundary cooperation*

Climate change features more clearly in the baseline assessment for SDG Indicator 6.5.2, which focuses on transboundary water resources management.[29] The baseline shows there is still significant room to increase commitments to climate change adaptation, and to the reduction of climate-related disasters, in transboundary cooperation: less than half (48%) of responses included climate change adaptation as part of the tasks and activities of the joint bodies responsible for transboundary cooperation. A similar share of responses (52%) included adaptation as an area of cooperation under operational transboundary arrangements. Around 75% included DRR (with a focus on floods and droughts) as part of tasks and activities of joint bodies, but flood was more emphasized as an area of cooperation under transboundary arrangements (78%) than drought (58%) (UNECE/UNESCO/UN-Water, 2018).

10.2.2 Water in nationally determined contributions

Chapter 2 of this report notes that water is the most often-cited priority sector in NDCs for adaptation actions (UNFCCC, 2016). A closer look, however, reveals the significant variations in *how* water features in NDCs. A region-by-region assessment of 80 countries' NDCs (GWP, 2018b) helps shed some light.[30]

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[28] Scored across 33 questions covering the main components of IWRM at both national and basin levels, organized in four sections: Enabling environment, institutional frameworks, management instruments and financing. Each question is scored 0–100 according to response, and scores are averaged. Scoring categories: 91–100 'very high', 71–90 'high', 51–70 'medium high', 31–50 'medium low', 11–30 'low', 0–10 'very low' (UN Environment, 2018). Data available for 172 countries; some double counting where countries are members of more than one region (as the chapter relates to climate change, Canada and the USA are counted as members of ECLAC, their nearer neighbours, and their membership of ECE is discounted; non-geographic associate membership is also ignored, e.g. European country membership of ESCAP or ECLAC). Total number of responses per region: ECA: 45; ECA/ESCWA: 6; ESCWA: 10; ECE: 44; ECE/ESCAP: 7; ESCAP: 31; ECLAC: 29.

[29] The Indicator 6.5.2 is the proportion of the transboundary basin area (river, lake or aquifer) within a country with an operational arrangement for water cooperation in place (UNECE/UNESCO/UN-Water, 2018).

[30] Country sample selected based on Global Water Partnership (GWP) network membership, with a focus on developing countries where NDCs included an adaptation component. Some countries are members of two RECs. Number of countries included per REC region: ECA: 31; ECA/ESCWA: 4; ESCWA: 2; ECE: 2; ECE/ESCAP: 6; ESCAP: 15; ECLAC: 20. It should be noted that the sample size for ESCWA (six countries) and ECE (eight countries) are particularly small and the conclusions on the analysis of NDCs for those regions are limited only to the data available and countries taken into consideration.

Box 10.1 Transboundary and regional climate–water initiatives – a European perspective

As 60% of global freshwater flows cross national boundaries, transboundary cooperation is essential for effective measures towards climate change adaptation (UNECE/INBO, 2015). The United Nations Economic Commission for Europe (UNECE) has emphasized this challenge clearly, publishing guidance on water and adaptation to climate change in 2009 (UNECE, 2009), and on Disaster Risk Reduction (DRR), water and adaptation in 2018 (UNECE/UNDRR, 2018).

Since the publication of the UNECE Guidance of 2009, numerous adaptation strategies and plans have been developed and implemented across basins in the ECE region (including the Chu-Talas, the Danube, the Dniester, the Neman and the Rhine) as well as globally (including Lake Chad, Lake Victoria, the Mekong and the Niger). These experiences show the potential for transboundary cooperation to enable enhanced adaptation planning at the country level by pooling resources, enlarging the planning space and reducing uncertainties. The ingredients for success include good communication, monitoring and data sharing, sectoral cooperation, capacity support, and funding mechanisms (UNECE/INBO, 2015). Sharing good practices in DRR and climate change adaptation more generally (including from a transboundary perspective) also helps build expertise, allowing countries and basins to learn from one another. While governments play a leading role, experience points to increasing engagement from civil society and private sector actors, either lobbying for certain interests (e.g. Dutch farmers' organizations on the Rhine) or as observers of international river commissions, such as the International Commission on the Protection of the Rhine (ODI/ECDPM/GDI, 2012).

Meanwhile, the European Union (EU) has been a driving force in framing and funding adaptation action at the regional level. A 2018 evaluation of the EU Adaptation Strategy identified water as one of six key sectors for integrating climate adaptation, and it found that the EU's Water Framework and Floods Directives provided for this (EC, 2018). Other analyses, however, point to the need for further integration of water policy and climate change adaptation in implementation of the EU's water-related Directives (Carvalho et al., 2019).

Water is less likely to feature in developed countries' NDCs, which have tended to focus on mitigation, with few including an adaptation component at all. Not embedding water in an NDC does not necessarily signify a wider lack of water–climate integration. The ECE region, for example, comprises many developed countries with little emphasis on water in their mitigation-focused NDCs, but has some of the strongest examples of transboundary and regional climate–water initiatives (Box 10.1). However, although water does not present the greatest opportunities for emissions reduction – as compared to energy, agriculture, forestry, land use or industry, for example – it is still surprising that water so rarely features as a central element in mitigation activities. There are crucial considerations and untapped opportunities: from the impacts of water-related climate change on mitigation efforts in other sectors (e.g. in hydropower, forestry), to emissions reduction in water distribution and wastewater treatment (New Climate Economy, 2018).

Good news: Institutional reforms are often prioritized along with infrastructure investments. In ECA, ESCAP and ESCWA countries, more than half of the NDCs that mention water-related measures describe activities that relate to both institution-building and infrastructure (Figure 10.2).[31] Investments to improve institutional capacity for water governance are an essential counterpart to investments in built infrastructure (GCA, 2019). While the specific type and sequencing of institutional vs. infrastructure investments necessarily varies between countries at different levels of development, an appropriate balance between the two ensures that trade-offs between equity, environmental and economic objectives can be managed in a changing climate (Sadoff and Muller, 2009; Shah, 2016). However, given that NDCs are partly used to set out needs for climate finance, which can incentivize countries to prioritize more costly infrastructure at the expense of institution-building, there is still room to improve the balance in all regions.

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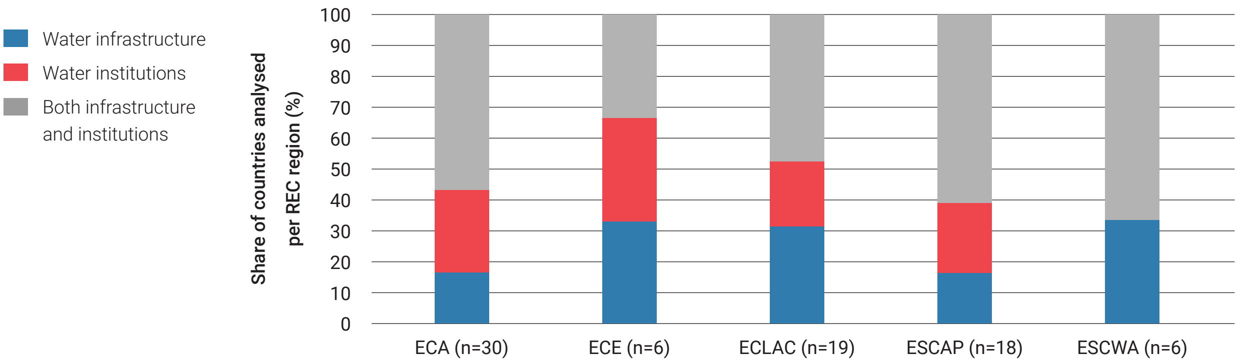
[31] Institutional measures include: water pricing; analysis or modelling to inform planning; regulation, standards and enforcement; and institutional development. Infrastructure measures include natural and built storage, infrastructure protection and desalination. Countries also mention actions that are harder to categorize as infrastructural or institutional, including general water resources management; water conservation measures (including ecosystem conservation, e.g. wetlands, water recycling, water use efficiency, and water harvesting); and actions relating to specific subsectors such as agricultural or urban water management, groundwater, and disaster risk reduction.

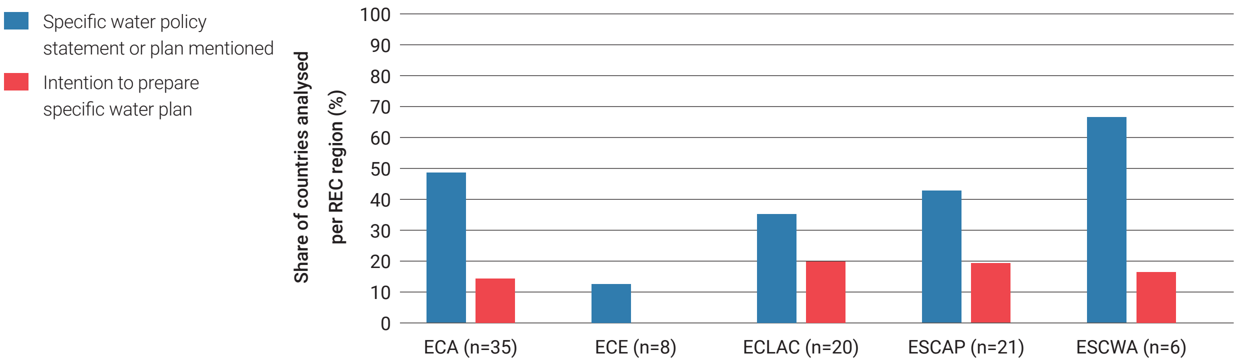
Figure 10.2 Prioritization of infrastructure vs institutional strengthening for water in NDCs



Source: Regional analysis of data on NDCs from GWP (2018b).

Ambiguous news: In several cases, countries' climate change strategists are aware of water sector plans – but in a good half of the countries this is not the case. Explicitly, water sector plans are mentioned in just over a third of the NDCs reviewed in the ECLAC countries, close to half of those in ECA and ESCAP, and four of six of the countries analysed in ESCWA (Figure 10.3). A further 14–20% of countries in each of these regions expressed an intention to prepare a water policy statement or plan, within their NDCs. This is testament to what can often be observed anecdotally: that in many countries, policy makers formulating the NDCs neither know nor are aware of the work done in the water sector. The agenda for action seems clear: ensuring that planning for water is adequately reflected within climate strategies.

Figure 10.3 Mention of water planning in NDCs

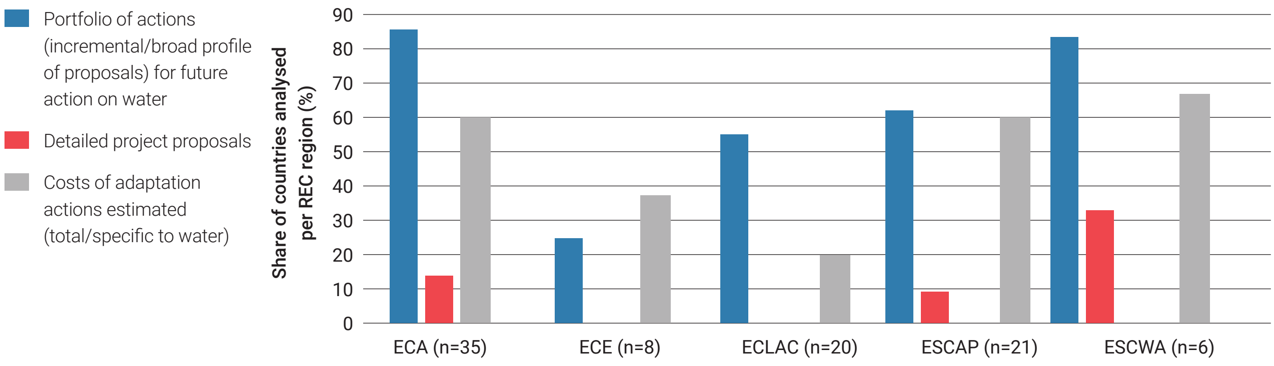


Source: Regional analysis of data on NDCs from GWP (2018b).

Concerning news: Significant regional differences in committing to water conservation. Water conservation measures are mentioned in 60% of the NDCs analysed in ECA and ECLAC, and in all of the NDCs analysed from ESCWA countries. However, only 24% of the ESCAP countries' NDCs mention them. Such water conservation measures include those based on natural infrastructure, such as wetlands and rainwater harvesting, both of which can help to smooth the variability of rainfall by storing water, with benefits for flood protection as well as water availability (Browder et al., 2019).

Most worrisome news: Across all regions there are few concrete project proposals that relate to water-relevant climate adaptation. Over 80% of the countries reviewed in ECA and ESCWA specify a broad portfolio of proposed actions in water in their NDCs, while only just over half of the countries in ECLAC and ESCAP do so (Figure 10.4). Across all regions, however, the share of countries referring to detailed water-related project proposals in their NDCs is much lower – under 20% of countries in ECA and ESCAP, two of the six countries analysed in ESCWA, and none of the countries in ECLAC, nor the eight countries

Figure 10.4 Water project portfolios, proposals and costings in NDCs



Source: Regional analysis of data on NDCs from GWP (2018b).

considered in ECE.[32] Since a robust pipeline of projects is a precondition for accessing needed finance (WWC/GWP, 2018), the limited mention of such projects in the first round of NDCs (pre-2020) does not bode well for swift implementation of these commitments. In all regions, countries are more likely to include (usually high) estimates of the costs of their intended adaptation actions than they are to mention detailed water project proposals. Importantly, while such costing exercises are essential, they very much depend on attention paid to methodological challenges, which is difficult to confirm in the absence of methodological details in many NDCs (Hedger, 2018a).

10.3 Sub-Saharan Africa – ECA perspective

10.3.1 Water-related climate change impacts on sectors and SDGs

Impacts of climate change on Africa's water resources are already acute. For example, numerous studies find that rainfall in southern Africa has decreased recently, probably as a result of climate change (IPCC, 2014a; Bellprat et al., 2015; Funk et al., 2018; Yuan et al., 2018). Such impacts will also increasingly interact with multiple non-climate-related drivers of water scarcity and water pollution, such as a growing population, economic development, and conflict and fragility, which are posing serious challenges for meeting not only the water targets but also the other development targets defined in the 2030 Agenda and the Africa Union's Agenda 2063. The impact of population increase will be particularly pronounced on the African continent, where the population has been predicted to grow by more than a half billion by 2050, increasing water stress, particularly in urbanizing regions (SDG 11) (Taylor et al., 2009). Water-related impacts of climate change on human health are also expected, through vector- and waterborne diseases (including by further challenging access to safe drinking water, sanitation and hygiene) and via malnutrition, given expected impacts on food security (SDGs 3 and 2) (IPCC, 2014a).

Generally, existing economic and livelihood practices, like natural ecosystems, are vulnerable in the face of climate change and poorly prepared to adapt without intervention. In agricultural systems, especially in semi-arid areas, conventional livelihood-based approaches appear not robust enough to deal with the long-term impacts of climate change (SDG 2) (IPCC, 2014a). Terrestrial and marine ecosystems, as well as coastal areas, are highly vulnerable to sea level rise, land-based runoff and storms and storm surges (SDGs 14 and 15) (CDKN, 2012; IPCC, 2014a).

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[32] Findings for the ECE region are likely an artefact of the low emphasis on adaptation action in this region's NDCs and the limited number of countries analysed.

The regional dimension of water-related climate change challenges is very strong across Sub-Saharan Africa, and it translates across multiple other challenges – including those relating to security and peace. Regional interdependence through hydropower in shared basins is high. By 2030, 70% and 59% of hydropower capacity in eastern and southern Africa is set to be located in one cluster of rainfall variability, respectively, increasing risks of concurrent disruption to power generation (Conway et al., 2017). At the same time, climate change drives migration within the region. Some of the current patterns of displacement can be directly linked to severe droughts (Owain and Maslin, 2018).

10.3.2 Policy responses: progress and challenges

The experience of water-related impacts of climate change in Sub-Saharan Africa is exacerbated by policy contexts that suffer from challenges in coordination as well as gaps in monitoring and research (IPCC, 2014a). This said, there have been important advances since the IPCC's *Fifth Assessment* (2014a), including efforts to build capacity for policy, implementation and evidence-informed decision-making through regional cooperation. One example is the Climate Resilient Infrastructure Development Facility (CRIDF), which aims to provide long-term solutions to water issues affecting poor communities in southern Africa. The facility has a strong emphasis on cross-border action, supporting national and regional stakeholders to undertake transboundary water sector projects by providing project preparation support, facilitating access to funding, and technical assistance (CRIDF, 2018). Another is the Climate Research for Development (CR4D) in Africa initiative, which seeks to tackle the persistent gap between climate data and decision-making across the region (Conway et al., 2015) by strengthening links between African climate science researchers and policy-makers (UNECA/ACPC, 2019).

> *The experience of water-related impacts of climate change in Sub-Saharan Africa is exacerbated by policy contexts that suffer from challenges in coordination as well as gaps in monitoring and research*

It is possible to prioritize water resources management in the context of climate change in key strategies, including adaptation plans, national economic development plans and NDCs, as indicated by a more in-depth review of three countries – Cameroon in Central Africa, Ghana in West Africa and Kenya in East Africa (Table 10.1). In all three countries, water resources management is prioritized in the NDCs, climate adaptation plans or planning frameworks. Importantly, water-related climate change is also recognized as a cross-sectoral issue in Cameroon's NDCs and Ghana's National Adaptation Plan (NAP) Framework – not as a concern for the water sector only, but for the country's economy as a whole. Ghana and Kenya also draw links between climate change and water resources management in their national development plans, though they are still generally addressed as separate sectors or themes.

The modest levels of IWRM implementation in all three countries nonetheless point to challenges ahead for multi-sectoral and integrated approaches to climate, water and development. Of concern is that water is not given adequate attention, beyond a brief mention, as a climate connector in the context of transboundary cooperation in the national development plans, NDCs or NAPs, despite the important context of shared rivers and lakes in all of the three countries.

10.3.3 Opportunities to accelerate water–climate action at national and regional scale

The list of policies and actions towards climate change adaptation and mitigation that include or involve water aspects is long. It includes supporting resilience to droughts and floods through investing in and improving the climate resilience of water supply, sanitation and hygiene (WASH) facilities (Oates et al., 2014); expanding social protection and introducing financial products like insurance (New Climate Economy, 2018); enhancing gender equality in the use and management of water resources (Das, 2017); and improving water availability for agriculture, including through water harvesting, mulching and reduced tillage in rainfed systems (Keys and Falkenmark, 2018).

Finding windows of opportunity to turn these priorities from a wish list into actions means paying close attention to political economy dynamics. Often, these have both national and regional dimensions, which determine the space for collaboration in institution-building, information and investment. For example, regional energy integration through power pools could reduce some of the climate vulnerabilities for hydropower in southern and eastern Africa, allowing for trade across pools and diversification of the energy generation mix within them. Energy is politically important to fulfil the ambitions of many African countries in terms of economic transformation. As such, it could provide a catalyst to encourage regional cooperation to address challenges at the water–energy–climate nexus, possibly opening up investment in regional power pools and the institutional mechanisms for energy trading. Political economy challenges to such solutions will need to be navigated, including national policies towards energy sovereignty, entrenched interests, inefficiencies in state monopolies and years of underinvestment in most countries (Conway et al., 2017).

There will always be opportunities where a clear business case for complementarity can drive regional cooperation. Regional insurance pools such as that developed by the African Risk Capacity (ARC) – a specialized agency of the African Union, of which Kenya, Ghana and 31 other states are members – allow countries to share the financial risk of drought with their neighbours. At the same time, the experiences of the countries in the sample show the importance of combining and sequencing regional-scale and national-scale action. The regional insurance mechanism needs to be backed up by country-level systems to channel pay-outs to those in need – for example, social protection systems that can transfer the pay-outs to poor farmers or pastoralists, before they have to sell off their assets in the event of drought (New Climate Economy, 2018). For such systems to be viable in the long term, members of the insurance facility need to be sufficiently dispersed geographically and climatically, so that droughts are unlikely to arise in all countries at once.

At the subregional scale, there are also opportunities to improve cooperation across river basins. Cameroon, Ghana and Kenya, as well as other African countries, participate in international projects in transboundary basins, including in the Niger, Volta and Lake Victoria basins (Table 10.1), in spite of the limited explicit attention to water–climate action with a transboundary character in their national climate and economic development strategies. This highlights the important role of basin and regional organizations as facilitators and implementers of water-related adaptation actions. It also indicates that there may be potential for transboundary cooperation on climate change to become a catalyst for strengthening the water dimension of national climate and economic planning (World Bank, 2017c).

10.4 Europe, Caucasus and Central Asia – ECE perspective

10.4.1 Water-related climate change impacts on sectors and SDGs

Climate projections indicate increasing precipitation in northern Europe and decreasing precipitation in southern Europe. A marked increase in high-temperature extremes, meteorological droughts and heavy precipitation events is projected, but with variations across Europe. Uncertainty is higher in Central Asia, with spatial variation in historic trends and inconsistency in projected changes for both precipitation and dryness/droughts. The IPCC highlights increasing challenges for irrigation, hydropower, ecosystems and human settlements in the Europe region (SDGs 2, 7, 11 and 15) (IPCC, 2014a). The possibility for both floods and droughts to amplify health challenges, such as water-related diseases, is also a key issue for the region (SDG 3) (UNECE/WHO Regional Office for Europe, 2011).

As in other regions, the water-related impacts of climate change also overlay regionally important social, economic and political drivers and stressors. Most important for the ECE region are the high and increasing level of development in many basins. For irrigation, for example, this means that demand will increase, but potential will be constrained not only by reduced runoff but also by increasing demand from other sectors (IPCC, 2014a). Other regionally important drivers can potentially facilitate climate–water integration – for example the comparatively strong political incentive provided by European Union (EU) membership and the resulting encouragement to comply with the Water Framework and Floods Directives (Box 10.1).

Table 10.1 Sub-Saharan Africa country snapshot: how water-related climate change is addressed in strategy and implementation

Country	IWRM implementation score (UN Environment, 2018)	Scale	National Plan	NDC	Adaptation Plan	Examples of key regional/ transboundary water–climate actions
Cameroon	34 (Medium low)	National	The *Document de Stratégie pour la Croissance et l'Emploi* (2010-2020) (Strategic Document for Growth and Employment) (Republic of Cameroon, 2009a) mentions climate change once; the focus with regards to water is WASH. The long-term strategy, Vision 2035, indicates that "the fight against the effects of climate change" will be a focus of Phase II (2020–2027), emphasizing forests, desertification and regional water bodies (Republic of Cameroon, 2009b).	The NDC includes a dedicated sectoral water programme focusing on various aspects of water-related climate change (e.g. WASH, resource management, floods, ecosystems, gender); water is also mentioned in programmes for agriculture and industry, and in a cross-cutting programme on hydro-meteorological data.	The *Plan National d'Adaptation aux Changements Climatiques du Cameroun* (2015) (Cameroon's National Plan for Climate Change Adaptation) (Republic of Cameroon, 2015) specifies the adaptation projects and programmes mentioned in the NDC in greater detail.	The project 'Integrated Development for Increased Rural Climate Resilience in the Niger Basin', funded by the Global Environment Facility, implemented by the African Development Bank and executed by the Niger Basin Authority, aims to increase water security and climate resilience in the basin, including through catalysing multi-state cooperation to balance conflicting water uses, considering climate variability and change.
		Transboundary	Vision 2035 includes promoting regional projects in the Niger River and Lake Chad basins as a priority for Phase II (2020–2027) under Axis 3.2 "Intensify the fight against climate change" (Republic of Cameroon, 2009b).	Not mentioned.	Transboundary organizations (Niger River and Lake Chad basins) are acknowledged, but activities do not appear to relate to transboundary water management.	
Ghana	49 (Medium low)	National	Area 2 (out of 5) of the Coordinated Programme of Economic and Social Development Policies (CPESDP) 2017–2024 is dedicated to environment, infrastructure and human settlements. Climate variability and change are recognized as important challenges for wetlands and water resources management. Priority responses include integrating water resources planning into national and subnational development planning.	Integrated water resources management is a specified policy action (of 7), with one corresponding programme of action (of 11) under Ghana's INDC adaptation goal.	The National Adaptation Plan Framework (2018) (EPA/NDPC/ Ministry of Finance of Ghana, 2018) indicates that water is expected to be one of the four cross-sectoral planning groups (alongside health, infrastructure, and the land, energy and agriculture nexus). A vulnerability assessment also identified water as a priority sector.	The project 'Integrating Flood and Drought Management and Early Warning for Climate Change Adaptation in the Volta Basin', implemented by the World Meteorological Organization and funded by the Global Adaptation Fund aims to assist Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo to implement coordinated and joint measures to improve existing management plans at the local, national and regional levels.
		Transboundary	Not mentioned.	Not mentioned.	Not mentioned.	
Kenya	53 (Medium high)	National	The Medium Term Plan (2018–2022) (Republic of Kenya, 2018) identifies climate change and disaster risk management as two of the three thematic areas; water resources management (under environment, water, sanitation and regional development) is considered separately. Climate change is recognized as a high-level general challenge to this objective.	Main identified climate hazards include droughts and floods. Priority adaptation strategies include mainstreaming of climate change adaptation in the water sector by implementing the National Water Master Plan (2014) (Ministry of the Environment of the Republic of Kenya, 2013).	Actions include "mainstreaming of climate change adaptation in the water sector" by strengthening water resource monitoring, conducting early warning assessments and planning, and promoting water efficiency. Water-related climate change impacts are also considered under health and energy.	The project 'Adapting to Climate Change in Lake Victoria Basin', funded by the Adaptation Fund, executed by the Lake Victoria Basin Commission and implemented by UN Environment, supports institutions to integrate climate resilience into transboundary water catchment management, among other activities.
		Transboundary	A flagship project on transboundary waters (negotiations, review and implementation of existing frameworks) is mentioned. No explicit link is made to climate change. Cross-border adaptation initiatives are mentioned under the thematic area 'climate change'.	Not mentioned.	Water action includes the medium-term sub-action to enhance collaboration in transboundary water resource management.	

Source: Authors

10.4.2 Policy responses: progress and challenges

The region comprises mainly advanced economies, with generally high levels of IWRM implementation (Figure 10.1). However, this is not universally the case. A deeper look at three middle-income countries – Kazakhstan, The Republic of North Macedonia and Ukraine (Table 10.2) – shows, firstly, that these countries have self-rated their progress in implementing IWRM as 'low' or 'medium low', indicating the need to improve water policies, institutions, management instruments and resources as a foundation for managing climate responses and impacts through water. Secondly, climate and economic strategies in Kazakhstan and Ukraine do not deal specifically with the links between climate change and water. While improving water management is recognized as a priority in the national development plans of all three countries, an explicit link to climate change is only made by the Republic of North Macedonia.

The Republic of North Macedonia's NDC is also the only one to mention water issues, namely hydropower. This lack of emphasis on water in the NDCs is partly explained by the fact that in all three countries the NDCs focus on mitigation – Kazakhstan and Ukraine, in particular, have high greenhouse gas (GHG) emissions. The National Communications are generally more detailed, and in Kazakhstan and the Republic of North Macedonia they treat water issues more extensively. Although no separate national-level adaptation plan was identified in either country, a concept for adaptation has been developed for Ukraine, containing several measures that relate to water.

Furthermore, Kazakhstan and Ukraine have been attempting to tackle climate and water as integrated issues at a regional level, within transboundary basins. The Dniester River is one of the largest basins in Ukraine and the largest in the Republic of Moldova, supplying water to a significant population and supporting a wide range of industries, including food, forestry and hydropower production. In 2015, high-level government representatives from the Republic of Moldova and Ukraine jointly signed a Strategic Framework for Adaptation to Climate Change, which was developed by expert representatives in consultation with environment, water and sectoral authorities from both countries, with the support of UNECE and the Organisation for Security and Co-operation (OSCE). The Strategic Framework identifies areas of joint actions at the basin level that require transboundary cooperation. The measures were further developed and financially assessed in the implementation plan for the Strategic Framework, and some have already been implemented. These activities have not only increased the adaptive capacity in the basin, but also promoted transboundary water cooperation more broadly, by facilitating the entry into force of the transboundary Dniester Treaty in 2017 and the establishment of the Dniester Commission in 2018.

In the case of Kazakhstan, meanwhile, climate adaptation planning in the Chu-Talas basin, shared with Kyrgyzstan, was enabled by careful facilitation and sequencing of activities, policy developments backed with concrete adaptation measures on the ground, and the engagement of local stakeholders as a route to influencing national decision-makers (Box 10.2).

These examples are not necessarily representative of the ECE region as a whole though. National reports on transboundary cooperation under the Water Convention (UNECE, 2018b) show that in less than a third of the responses climate change adaptation was included as an area of cooperation under the activities of the joint bodies and operational transboundary arrangements. At the same time, there was frequent inclusion of flood and drought risk management (up to 85% of the responses) as an area for cooperation under both joint bodies and operational transboundary arrangements. While recent climate extremes have therefore been a focus for transboundary cooperation, there is room to increase the focus on adaptation in many basins.

10.4.3 Opportunities to accelerate water–climate action at the national and regional scale

The key actions for more effective adaptation and more resilience to extremes in the region, both within individual countries and in transboundary basins, include: integrated management of water resources, including across country boundaries; enhanced water efficiency and water saving strategies (IPCC, 2014a); monitoring and data sharing on water quantity and quality as well as disasters as a basis for climate change adaptation strategies, plans and measures; improving coherence of climate change adaptation and water-related DRR (UNECE/UNDRR, 2018); translating strategies and agreements into practice through traditional and innovative actions, including nature-based solutions (NBS) (UNECE/INBO, 2015); and attracting and combining funding from multiple sources (e.g. international, national and private), including for climate change adaptation in transboundary basins (World Bank, 2019).

Table 10.2 Europe, Caucasus and Central Asia country snapshot: how water-related climate change is addressed in strategy and implementation

Country	IWRM implementation score (UN Environment, 2018)	Scale	National Plan	NDC	Adaptation Plan	Examples of key regional/transboundary water–climate actions
Kazakhstan	30 (Low)	National	Water challenges and policy responses are included in Strategy 2050, but not in context of climate change (Republic of Kazakhstan, 2012).	The NDC focuses on mitigation. No mention is made of water resources. The latest National Communication (VII, 2017) extensively considers water-related impacts and adaptation options (Ministry of Energy of the Republic of Kazakhstan/ UNDP in Kazakhstan/GEF, 2017).	A National Adaptation Plan is in development. As noted, water-related adaptation actions have been identified in the National Communication.	The Chu-Talas Water Commission and its dedicated Working Group on Adaptation to Climate Change and Long-Term Programmes, with support of UNECE, UNDP and the Organization for Security and Co-operation in Europe (OSCE), integrate climate change adaption into planning processes in the basin shared by Kazakhstan and Kyrgyzstan (Box 10.2).
		Transboundary	Water is recognized as a geopolitical issue in the Strategy 2050, but not in the context of climate change.	Transboundary legislation and cooperation have been identified as an adaptation measure in National Communication VII (2017).	No adaptation plan as yet.	
Republic of North Macedonia	22 (Low)	National	The increasing susceptibility to disasters due to climate change has been recognized. Most priority responses are water-related, including an integrated system for water management through a dedicated water agency, flood protection planning and early warning systems.	The NDC focuses on mitigation. Small and large hydropower is mentioned under mitigation measures. National Communication III (2014) considers climate change impacts on water, adaptive capacity and adaptation measures in the water sector in detail. Integrated, cross-sectoral and basin-oriented water resources management is an overarching priority (Ministry of Environment and Physical Planning of the Republic of Macedonia, 2014).	A National Adaptation Plan is in development. As noted, water-related adaptation actions have been identified in the National Communication.	The Republic of North Macedonia cooperates with its neighbours to ensure sustainable management of the Drin basin with support of the GWP, UNECE and UNDP. The riparians foresee climate change as a cross-cutting issue and try to take it into account while dealing with such issues as deterioration of water quality, variability of hydrological regime, biodiversity degradation and sediment transport.
		Transboundary	Transboundary rivers are mentioned (e.g. Vardar), but transboundary water management dimensions are not.	Not mentioned in the INDC. Potential for transboundary cooperation on adaptation in the Strumica River basin is noted.	No adaptation plan as yet.	
Ukraine	39 (Medium low)	National	Sustainable water management and climate change prevention and resilience are separate priority actions within the Government Priority Action Plan to 2020. Climate–water interlinkages do not appear to be explicitly considered, although the priority actions on climate change and adaptation include vulnerability assessments for different sectors (Cabinet of Ministers of Ukraine, 2017).	Water is not mentioned in the NDC. The latest National Communication (VI, 2013) focuses on mitigation. It mentions water, but not water resources (Ministry of Ecology and Natural Resources of Ukraine, 2013).	The Concept of State Climate Change Policy Implementation until 2030 (2016) and its Action Plan (2017) foresee development of sectoral adaption policies and plans covering integrated water resource management, disaster risk reduction and water-related sectors, and include adaptation measures into river basin management plans (Cabinet of Ministers of Ukraine, 2016).	The entry into force of the Dniester Treaty in 2017 and the establishment of the Dniester Commission in 2018 were facilitated in part by the development of a Strategic Framework for Adaptation to Climate Change by the Republic of Moldova and Ukraine, with support of UNECE and the OSCE. The Commission foresees climate change adaptation as part of the transboundary management plan for the basin, as well as through reducing disaster risk from floods and droughts and implementation of adaptation measures.
		Transboundary	Transboundary freshwater issues are taken into account through application of the basin approach in integrated water resource management.	Transboundary water issues are not mentioned in the NDC, nor in the latest National Communication.	Not explicitly mentioned.	

Source: Authors

Box 10.2 Lessons from integrating climate change adaption into planning processes in the Chu-Talas basin in Kazakhstan and Kyrgyzstan

The Chu and Talas Rivers are the major sources of water for agriculture and they support the livelihoods of more than three million people in Kazakhstan and Kyrgyzstan. The Chu-Talas basin is highly vulnerable to climate change, with a likelihood of increasing aridity and overall declining water availability (UNECE/UNDP, 2018).

Initial climate change adaptation activities started in the basin in 2010 with modelling of climate change impacts and a vulnerability assessment, which was then elaborated into a set of climate change adaptation measures, covering issues from water quality to monitoring and education. These were further assessed against their cost/effectiveness and integrated into a transboundary diagnostic analysis (TDA) and a Strategic Action Program (SAP). The SAP, when approved, will become the main document for transboundary management in the basin, facilitating cooperation, planning, funding and implementation. Lessons from the process include:

- Joint bodies play a crucial role for climate change adaption in transboundary basins. A Joint Bilateral Chu-Talas Water Commission allowed for discussing problems and finding solutions.
- Transboundary adaptation strategies can support national adaptation, sectoral strategies and nationally determined contributions (NDCs), and vice versa. For example, sectoral climate change adaptation plans for disaster risk reduction, forestry, biodiversity, agriculture and water resources in Kyrgyzstan were developed in coordination with (and complemented by) the transboundary adaptation activities in the Chu-Talas basin.
- Strategic documents can be backed by demonstrated implementation of adaptation measures. Reforestation, public awareness and sustainable irrigation on the ground in Kyrgyzstan complemented the integration of climate change into the TDA and SAP.
- Involving local stakeholders in discussing adaptation measures helps communication with decision-makers at national and transboundary levels, given that implementation of the adaptation measures often takes place at the local level.

Source: UNECE (n.d.).

However valid they are, these prescriptions remain a wish list for many countries in the region. Costs of adaptation in the water sector of the ECE region can be high. Assessment of adaptation costs, performed as part of the adaptation strategies and plans for selected basins (the Chu-Talas, the Dniester and the Neman River basins), revealed that the approximate costs for adaptation among the water-related sectors amounted to roughly €200 million each (UNEP/UNECE, 2015; UNECE, 2017; ENVSEC/UNECE/OSCE, 2017). However, the funding gap can also be lower, given that the region is comparatively wealthy and the costs are (or will be) already partly covered by the relevant sectoral programmes and projects.

This points to a window of opportunity created by the diversity of economies in the region. When it comes to improving water–climate integration in transboundary basins, technical and financial assistance can be shared up- or downstream, from wealthier to poorer riparian countries. As an example, the Danube basin is shared by some of the wealthiest as well as some of the poorest countries in Europe. Here, the International Commission for the Protection of the Danube River (ICPDR) is a leader among transboundary river basin commissions in responding to climate change. The first Strategy on Adaptation to Climate Change for the Danube basin was developed in 2012. Based on this, the ICPDR fully integrated climate adaptation issues in the Danube River basin and Flood Risk Management Plans in 2015. The strategy was updated in 2018, including a review of the knowledge base, stakeholder consultations and necessary efforts, in order to reflect the latest science as well as evolving legislative and policy instruments at the EU and the country levels. To encourage integration of climate change adaptation into Danube basin planning processes, the ICPDR has made climate change adaptation a mandatory issue to incorporate into updated Danube River basin and Flood Risk Management Plans. The strategy also promotes multilateral and transboundary cooperation action in the context of climate change adaptation (ICPDR, 2019), serving as a common reference for national policy-makers from countries at different stages of development.

This said, even where funds are available, transboundary water management can be politically difficult. This points to the need to find a politically salient entry point around which to build cooperation. In some cases, climate change itself can be the factor that opens up the opportunity for cooperation on transboundary management – as was the case on the Dniester.

10.5 Latin America and the Caribbean – ECLAC perspective

10.5.1 Water-related climate change impacts on sectors and SDGs

Changes in climate variability and extreme events already severely affect Latin America and the Caribbean. In South and Central America, streamflow and water availability changes are observed and projected to continue, affecting already vulnerable regions. In South America, retreat of the Andean cryosphere will change seasonal streamflow distribution. The IPCC predicts with high confidence that water supply shortages will increase in already vulnerable semi-arid regions, with reduced precipitation and increased evapotranspiration, affecting cities, hydropower generation and agriculture (SDGs 11, 7 and 2) (IPCC, 2014a). Increasing dryness is also expected in Central America and Mexico, though with lower confidence in the south of the subregion. In the Caribbean subregion, drought risk is projected to increase, especially if temperatures rise with more than 1.5°C. The Caribbean islands also face threats from sea level rise, including salinization, flooding and pressure on ecosystems (SDG 14) (IPCC, 2018b).

Rapid urbanization, economic development and inequality are among the key socio-economic drivers of pressure on water systems in Latin America and the Caribbean with which water-related climate impacts intersect. Poverty is persistent in most countries in the region, contributing to the vulnerability to climatic change. Economic inequality also translates into inequality in access to water and sanitation, and vice versa. Increasing risks of waterborne diseases with climate change (IPCC, 2014a) have a greater impact on poor people (SDGs 1 and 3). In the face of economic development priorities, water is needed to meet both sectoral (domestic, agriculture, energy) and ecosystem needs, posing persistent challenges for sustainable water resources management. Countries in South and Central America meet 60% of their energy demand through hydropower, while at the same time land use change for food production and bioenergy exerts pressure on water resources (SDG 15) (IPCC, 2014a). Over 80% of the region's population lives in urban areas (UNDESA, 2019), and droughts have been linked to reduced employment and labour incomes in Latin American cities (SDGs 8 and 11) (Desbureaux and Rodella, 2019). Vulnerability to water-related impacts of climate change is also high in rural areas, with climatic factors limiting economic options and driving out-migration. For example, in 2014, a significant increase in the number of Guatemalans seeking access to the United States of America (USA) coincided with the onset of El Niño-related drought conditions in the Central American Dry Corridor (Steffens, 2018). Climate change is expected to intensify drought risk here, forcing more poor rural families to migrate out of the region (SDG 10) (UNECLAC, 2018).

10.5.2 Policy responses: progress and challenges

A more in-depth assessment of three countries from across the region – Chile in South America, Grenada in the Caribbean and Guatemala in Central America (Table 10.3) – illustrates some of the progress and remaining challenges facing ECLAC countries in tackling climate change through water. The countries' climate strategies – as evidenced in Adaptation Plans and NDCs – reveal some positive intentions. For example, Chile and Guatemala's NDCs recognize water-related impacts and response measures across multiple sectors. Grenada's NAP's Programme of Action 3 (out of 12) aims to establish a 'climate-responsive water governance structure', recognizing the need for institutional development across planning, policy and information systems, alongside infrastructure.

The selected countries' national development plans tend to recognize water-related impacts of climate change and in some cases the importance of water management to economic development. However, they do not explicitly treat water management and climate change as interlinked sectors requiring integrated responses. Moreover, despite the cross-sectoral treatment of water issues in the countries' climate strategies, their progress in implementing IWRM suggests there will be challenges in integrating water and climate action in practice. All three countries self-rate 'low' in IWRM implementation in the SDG 6.5.1 baseline assessment, as do close to half of the countries across the region (Figure 10.1).

Considering transboundary aspects, none of the three strategies examined for Chile and Guatemala address water as an international climate connector across transboundary basins (Grenada has no transboundary basins).

Table 10.3 Latin America and the Caribbean country snapshot: how water-related climate change is addressed in strategy and implementation

Country	IWRM implementation score (UN Environment, 2018)	Scale	National Plan	NDC	Adaptation Plan	Examples of key regional/transboundary water–climate actions
Chile	23 (Low)	National	'Chile Agenda 2030' outlines a reform and action agenda including laws, plans, programmes and other initiatives in order to achieve SDG 6. Existing climate change impacts, including in terms of water scarcity, are recognized (ChileAgenda2030, n.d.).	NDC actions for adaptation focus on implementation of the National Adaptation Plan and seven sectoral plans (including for water resources; while one for forestry and agriculture is also noted to focus on water management)	The National Adaptation Plan recognizes water-related impacts, especially on farmers of dryland areas via the use and management of water resources; and the role of high-altitude ecosystems in ensuring water supply. Multisectoral dependence on water resources is recognized and other sectors, including infrastructure, rural development and energy, are identified as strategic entry points to improve IWRM (Ministry of Environment of Chile, 2014).	No current transboundary water management projects with a strong climate change dimension have been identified. The Adaptation Fund has endorsed the concept for a regional disaster risk reduction project, 'Enhancing Adaptive Capacity of Andean Communities through Climate Services (ENANDES)', supporting Andean communities in Chile, Colombia and Peru. This document includes a component on regional–national climate monitoring, forecasting and decision-making.
		Transboundary	Not explicitly mentioned.	Not explicitly mentioned.	Not explicitly mentioned.	
Grenada	25 (Low)	National	The Growth and Poverty Reduction Strategy 2014–2018 recognizes vulnerabilities to climate change and other factors and, in this context, the need for the nation's environmental management agenda to include integrated coastal zone management and freshwater ecosystem protection, among others (Government of Grenada, 2014).	Adaptation actions include improving water resource management, which is recognized as a crucial element for the long-term development of Grenada. Water is also identified as the dominant cross-cutting sector in Grenada's Technology Needs Assessment.	The National Adaptation Plan mentions a vulnerability assessment of the water sector. It also includes action on establishing a climate-responsive water governance structure, with targets to improve institutional mechanisms for planning, management and efficient use of water resources. Water is also mentioned under agriculture and ecosystem actions (Government of Grenada, 2017).	No transboundary basins. The project Climate-Resilient Water Sector in Grenada (G-CREWS), funded by the Green Climate Fund (Remove (GCF) and executed by GIZ, the Grenada Development Bank and Grenada's Ministry of Finance, Energy, Economic Development, Planning and Trade, includes an additional component, funded by the German Government, for regional learning and replication.
		Transboundary	No transboundary basins.	No transboundary basins.	No transboundary basins.	
Guatemala	25 (Low)	National	*'Plan Nacional de Desarollo K'atun: nuestra Guatemala 2032'* (K'atun 2032 National Development Plan) includes separate goals for climate change (adaptation and mitigation) and water resources management. IWRM is included in relation to forests, energy and water, and recognized as central for sustainable national development (National Council of Urban and Rural Development, 2014).	Water-related climate change impacts are recognized, and IWRM is listed as one of the priority actions in order to strengthen adaptation to climate change. Under mitigation, IWRM is also recognized in the agriculture and the waste sector.	No National Adaptation Plan. The National Climate Change Action Plan (2016) includes a chapter on adaptation. IWRM is identified as a key pillar. Relevant action goals include increasing access to drinking water, treating wastewater, quality and quantity control in river basins, sustainable protection of climate vulnerable areas/basins, and establishment of operative instruments in a new Water Law (National Council on Climate Change, 2016).	No current transboundary water management projects with a strong climate change dimension have been identified. Guatemala is part of the regional project 'Productive Investment Initiative for Adaptation to Climate Change (CAMbio II)', funded by the GCF and co-financed and executed by the Central American Bank for Economic Integration (CABEI). This project aims to increase the resilience of micro-, small- and medium-sized enterprises in Central American countries by removing barriers to access to financial and non-financial services (including water access).
		Transboundary	The importance of addressing cross-border spaces, including strategic watersheds, is noted, with a view to ensuring that the population has sustainable livelihoods.	Not explicitly mentioned.	Not explicitly mentioned.	

Source: Authors

10.5.3 Opportunities to accelerate water–climate action at the national and regional scale

For many countries in the region, climate change occurs against a backdrop of high levels of intersectoral competition for water, including between urban areas, the energy and agriculture sectors, and ecosystem needs. These countries therefore need to avoid the risk of maladapted responses. Modelling of NDC commitments in Argentina, Brazil, Colombia and Mexico identified that mitigation pledges could exacerbate conflicts regarding the use of energy, water and land resources – principally due to increased water demand for electricity generation and crop and biomass irrigation (Da Silva et al., 2018). The nascent signs of policy integration across water, climate and other SDGs in the countries in Table 10.3 are a first step towards managing trade-offs. However, slow progress implementing IWRM suggests a need for renewing effort. In this respect, UNECLAC and the German Agency for International Cooperation GmbH (GIZ) have had some success utilizing water–energy–food nexus framings as an entry point for policy dialogue in the region – for example in helping Costa Rican policy-makers tackle long-running conflicts between different uses such as hydropower and irrigation in the Reventazón River basin (Jouravlev, 2018).

Countries in the region will also need to find additional funds to make progress towards their water goals while ensuring that enough water is available for their other development goals, and while adapting their water-related systems and infrastructure to climatic changes. Climate Change Policy Assessments (CCPA), jointly supported by the International Monetary Fund (IMF) and the World Bank, can help countries manage their climate response through a macroeconomic and fiscal lens. A recently completed CCPA for Grenada suggests that the Government needs to improve its fiscal position and reduce debt levels and financing needs, by making further reforms to its Fiscal Responsibility Law. This would in turn provide more space for climate-related investment, for example in resilient infrastructure. Grenada's policy and legal frameworks can also be improved to attract private investment into relevant sectors for climate change adaptation and mitigation (IMF, 2019), including water.

At the regional level, the limited explicit mention of transboundary water–climate issues in Chile and Guatemala's climate and development strategies is symptomatic of wider challenges in cooperation on transboundary waters in Latin America and the Caribbean – at least as defined against SDG Indicator 6.5.2. The Indicator 6.5.2 baseline assessment estimated that only a quarter of transboundary basin areas (river, lake or aquifer) were covered by operational arrangements for water cooperation.[33] Only one country, Ecuador, has operational agreements in place for all its transboundary basins (UNECE/UNESCO/UN-Water, 2018).

The very same baseline assessment points to opportunities to couple efforts to enhance transboundary cooperation with other issues, including climate change, helping to catalyse dialogue and to ensure that synergies are maintained. Central American countries have already had some success embedding transboundary water cooperation arrangements within wider treaties, for example on environmental protection. Examples include the arrangements between Guatemala, Honduras and El Salvador, and between Guatemala and Mexico (UNECE/UNESCO/UN-Water, 2018). The progress of using climate change as an entry point to broader transboundary cooperation, like the cooperation in the Dniester River basin highlighted in the preceding section, points to similar potential in the ECLAC region.

10.6 Asia and the Pacific – ESCAP perspective

10.6.1 Water-related climate change impacts on sectors and SDGs

There is high variation and low confidence in projected water-related impacts of climate change at the subregional scale in Asia and the Pacific (IPCC, 2014a). Water-related climate impacts intersect with other socio-economic trends that impact water quality and quantity, including industrialization (which is reshaping sectoral demand for water and increasing pollution), population growth and rapid urbanization. The latter have also increased exposure to water-related natural hazards such as floods (UNESCAP/UNESCO/ILO/UN Environment/FAO/UN-Water, 2018).

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[33] Estimated for 12 countries (Brazil, Chile, Colombia, the Dominican Republic, Ecuador, El Salvador, Honduras, Mexico, Panama, Paraguay, Peru and Venezuela).

The region is highly vulnerable to climate-induced disasters and extreme weather events, which are disproportionately burdening poor and vulnerable groups (SDGs 1 and 11) (UNDRR/UNFCCC/UN Environment Regional Office for Asia and the Pacific, 2019). In August 2017 alone, intense monsoon rains affected 40 million people in Bangladesh, India and Nepal, claiming nearly 1,300 lives and putting 1.1 million people in relief camps. Floods could cost South Asia as much as US$215 billion each year by 2030 (UNESCAP/ADB/UNDP, 2018). Floods are also expected to contaminate water sources, destroy water points and sanitation facilities, and therefore pose a challenge to universal access to sustainable water and sanitation services (SDG 6) (UNESCAP/UNESCO/ILO/UN Environment/FAO/UN-Water, 2018).

Climate change and increasing demand for water will put stress on the region's groundwater resources, as the availability of surface water is affected by increasing climate variability. Groundwater use in the region could increase by 30% by 2050 (ADB, 2016). The increase in demand for irrigation has already led to severe groundwater stress in some areas, especially in two of Asia's major 'food baskets' – the North China Plain and Northwest India (SDG 2) (Shah, 2005).

10.6.2 Policy responses: progress and challenges

A more in-depth assessment of three countries across the region – Bangladesh, China and Indonesia – illustrates the differing degrees of progress on tackling water and climate change in an integrated manner (Table 10.4). Bangladesh and Indonesia rate their progress on implementing IWRM lower than China. Concluding from its national development plan, NDC and adaptation plans, Bangladesh appears to have gone relatively far in ensuring that water and climate change are approached synergistically. Water issues are also recognized in China and Indonesia's climate strategies, even though integrated treatment of water and climate is less evidenced in their national development plans than it is for Bangladesh.

The desk-based analysis for this chapter did not identify any transboundary initiatives with a strong climate change dimension in the three countries of the sample, though this may correspond with a wider gap in reporting on transboundary cooperation across the Asia region (UNECE/UNESCO/UN-Water, 2018). Transboundary water issues are briefly mentioned in the national development plans of Bangladesh and China, but were not identified in their respective climate strategies.

10.6.3 Opportunities to accelerate water–climate action at the national and regional scale

At the national level, identified priorities include: enhancing water governance and water productivity to manage competition between the water needs of agriculture, energy, industry, cities and ecosystems (ADB, 2016; IPCC, 2014a); promoting NBS that can curb emissions and increase resilience (IPCC 2018b); and integrating climate change and DRR across the entire project and policy cycle (UNDRR/UNFCCC/UN Environment Regional Office for Asia and the Pacific, 2019).

Climate change could have a negative effect on the required integration of policy-making and delivery, adding uncertainty and complexity, and making it harder to achieve these priorities. However, climate change can also help catalyse policy reforms that respond to wider pressures on water, and open up opportunities for action on these kinds of long-standing challenges for water management. One example comes from the North China Plain, one of China's most important food-growing areas and home to more than 400 million people (Kang and Eltahir, 2018). Here, the threat of climate change partly justifies a concerted response to declining groundwater levels, even though the immediate driver of change is intensive irrigation. In Hebei province, for example, abstraction is being measured indirectly via energy consumption (electricity meters on pumps); new hydrogeological models are being used to predict the response of the groundwater system to changes in abstraction, rainfall and longer-term climatic conditions; and economic and regulatory levers are being used to bring withdrawals in line (gradually) with projected water availability. Not all actions are popular with farmers, but climate change provides a politically neutral rationale to drive water policy dialogue and reform (Li et al., 2018).

> *Climate change can also help catalyse policy reforms that respond to wider pressures on water, and open up opportunities for action on these kinds of long-standing challenges for water management*

As in other regions, cooperation between countries will help drive and strengthen national actions. In the area of investment, an estimated incremental investment of US$21–47 billion by 2030 is needed to make water and sanitation infrastructure climate-resilient across Asia and the Pacific. Many countries, including Small Island Developing States (SIDS) and Least Developed Countries (LDCs), face not only a shortfall in finance but also difficulty in accessing and attracting funds. These countries will need support to increase investment readiness, for example in order to help prepare a pipeline of fundable projects. This assistance can come from international and regional organizations but can also be further enhanced through cross-country exchanges among countries in Asia and the Pacific (UNDRR/UNFCCC/UN Environment Regional Office for Asia and the Pacific, 2019).

Regional cooperation on investment and information, as well as on institutional areas such as governance, capacity and partnerships, is urgently needed in Asia's transboundary basins. These basins face enormous challenges resulting from development – including urbanization, hydropower and pollution – and from climate change.

Bangladesh, for example, comprises the largest delta in the world. It lies at the confluence of three major global rivers draining land in Bhutan, China, India and Nepal, but has only 7% of the catchment area of these basins (Rasheed, 2008). The current national development plan recognizes that Bangladesh cannot undertake meaningful water resource development programmes on its own and aims to strike new transboundary agreements (Table 10.4). So far, however, a water-sharing agreement is in place for only one of its 57 transboundary rivers – the Ganges, with India (UN Environment, 2017). More progress has been made on tackling water-related climate issues in the Mekong River basin, which is expected to be home to 83 million people by 2060 (MRC, 2016). This shows how climate change has provided a focal point for regional cooperation, but also illustrates how it can further complicate integrated management, for example by creating additional trade-offs around hydropower (Box 10.3).

Box 10.3 Climate change – complicating and driving transboundary cooperation on the Mekong

The Mekong River basin has seen energetic efforts to develop transboundary responses to climate change, especially in the lower basin. Here, significant infrastructural and socio-economic changes are already exerting huge pressure, including dams that disrupt environmental flows, as well as fish migration (Evers and Pathirana, 2018). In addition, the El Niño effect and climate change are causing the monsoon season to shorten. In 2019, water levels dropped to their lowest level in 100 years, although water management decisions upstream, including retention of flows for hydropower, were also an exacerbating factor (Lovgren, 2019).

In the Lower Mekong basin, member countries of the Mekong River Commission (MRC) – Cambodia, Lao People's Democratic Republic, Thailand and Viet Nam – developed the Mekong Climate Change Adaptation Strategy and Action Plan (MRC, 2018). As an example of climate change adaptation, offering a focal point and enabler for transboundary cooperation on water, the Strategy sets out seven strategic priorities, including: mainstreaming climate change into national and regional policy, planning and programming; supporting access to adaptation finance; and enhancing regional and international partnerships and cooperation on adaptation (MRC, 2018).

Implementing full transboundary adaptation on the Mekong will be challenging. China, whose territory constitutes around a fifth of the basin and which contributes 16% of the Mekong River basin flow is not a member of the MRC, and nor is Myanmar, which also accounts for a small share of the territory and flow (Evers and Pathirana, 2018). All countries have justified development ambitions, for which water is essential. While energy security is often a major consideration for countries developing their hydropower resources, emissions mitigation can also be used to justify hydropower developments, illustrating how climate change can complicate existing trade-offs in water management. The science on the climate-related benefits and costs of hydropower are, moreover, uncertain: greenhouse gas (GHG) emissions from the Mekong's hydropower have been found to vary significantly (Räsänen et al., 2018), as have the projected impacts of climate change on hydropower production, via changes in runoff (MRC, 2018). Such uncertainties need to be properly addressed through appropriate and robust options appraisal, which must also incorporate the value of ecosystem services as well as the species that depend on the river and its natural flows. The MRC and member countries' efforts on climate change adaptation are an important start, however, and offer a signal for scaling up cooperation on climate change in transboundary basins across Asia.

Table 10.4 Asia and the Pacific country snapshot: how water-related climate change is addressed in strategy and implementation

Country	IWRM implementation score (UN Environment, 2018)	Scale	National Plan	NDC	Adaptation Plan	Examples of key regional/transboundary water–climate actions
Bangladesh	50 (Medium low)	National	The Seventh Five Year Plan (2016–2020) includes separate strategies for agriculture and water resources, and sustainable development, environment and climate change. Climate change is recognized as one of the ten challenges for the water sector and one of the fourteen water sub-strategies. In the context of the 100-year Delta Plan (BDP 100), building a climate-resilient society is recognized as a first challenge for the water sector (Government of the People's Republic of Bangladesh, 2015). Climate change screening tools have also been integrated into Annual Development Plans (ADPs).	The NDC identifies an adaptation goal with ten key areas of action, of which eight relate to water management issues, even though water linkages are not always explicitly stated. These areas include food security, disaster management, coastal zone management, and community-based conservation of wetlands and coastal areas.	Bangladesh was one of the first LDCs to submit its National Adaptation Programme of Action (NAPA) in 2005. It was updated in 2009. The Bangladesh Climate Change Strategy and Action Plan (BCCSAP) was approved in 2009, and ran until 2018. Most of the 44 priority programmes have direct or indirect links to water management. They include crop improvement, drought management, disaster management, and infrastructure and knowledge management (Ministry of Environment and Forests of Bangladesh, 2009). A National Adaptation Plan is in preparation.	No current transboundary water management projects with a strong climate change dimension have been identified. Bangladesh is a Party to the Ganges Water Sharing Treaty (1996) with India, which aims to ensure the dry season flow in the Ganges River (Government of the Republic of India/ Government of the People's Republic of Bangladesh, 1996). Arrangements between Bangladesh and India on water-related DRR, including sharing flood-related data of transboundary rivers, have also been made within the Statute of the Indo-Bangladesh Joint Rivers Commission (1972). However, there are no water-sharing agreements for the 56 other transboundary rivers, besides the Ganges.
		Transboundary	The National Plan highlights that Bangladesh is dependent on upper riparian countries for meaningful and comprehensive water resources development. Bangladesh had the intention to immediately enter into agreements with co-riparian countries for sharing the waters of international rivers, data exchange, resource planning and long-term management of water resources, under normal and emergency conditions. Explicit links are made to current water extremes but not to climate change.	No explicit mention.	No explicit mention.	
China	75 (High)	National	In China's Five-Year Plan (2016–2020), a priority is to strengthen water security, including through a more efficient use of water resources. The document outlines water security projects that all contribute to "comprehensive flood control and mitigation systems". Other areas of intervention include protection of water resources and the control of water pollution through IWRM.	Water resources is a key area of focus for adaptation, where enhancing climate resilience will involve optimizing the allocation of water resources whilst implementing the strictest water management regulation.	In the National Adaptation Strategy (NAS), water resource management is identified as a priority area. A variety of conservation, ecological restoration and use strategies are being promoted to help the water sector adapt while managing complex demands (National Development and Reform Commission, 2013).	No current transboundary water management projects with a strong climate change dimension have been identified. China cooperates with Parties to the Mekong Agreement (Box 10.3), but is not a Party itself. It has separately initiated the Lancang-Mekong Cooperation with the five other Mekong riparians. The Five-Year Plan of Action on Lancang-Mekong Cooperation (2018–2022) mentions climate change briefly in relation to 'non-traditional security cooperation' and 'water resources'
		Transboundary	The National Plan recognizes the ambition to implement well-planned steps to develop and harness the water of cross-border river basins, and deepen cross-border water cooperation with neighbouring countries.	No explicit mention.	No explicit mention.	
Indonesia	48 (Medium–low)	National	*Indonesia's Five-Year Strategic Plan* (RPJMN 2015–2019) recognizes climate change as a cross-sectoral threat. Water security is a priority goal. The document lists activities to improve watershed conservation, water availability, and access to drinking water and sanitation (Republic of Indonesia, 2014a). The RPJMN for the period 2020–2024 is currently under development.	Water security is recognized as an enabling condition for climate resilience. The NDC refers to enhanced action on integrated watershed management for economic resilience, as well as ecosystem and landscape resilience.	Rancana Aksi National – Perubahan Iklim (RAN-API, 2014), Indonesia's National Adaptation Plan, includes management of water quality and water pollution control, consumption saving and management of water demand, and utilization of water resources in a fair, efficient and sustainable way, as key strategies (Republic of Indonesia, 2014b).	No current transboundary water management projects with a strong climate change dimension have been identified.
		Transboundary	Not explicitly mentioned.	Not explicitly mentioned.	Not explicitly mentioned.	

Source: Authors

10.7 Western Asia and North Africa – ESCWA perspective

10.7.1 Water-related climate change impacts on sectors and SDGs

Vulnerability to climate change is moderate to high across the region, with a generally increasing gradient from north to south. This is a headline finding of the RICCAR, an important example of a region-specific impact and vulnerability assessment with a strong focus on water-related impacts. RICCAR projects largely decreasing precipitation trends across the region until the end of the century. Runoff and evapotranspiration generally follow the same trends as precipitation, although evapotranspiration is limited by water scarcity constraints in some areas. Temperatures in the Arab region are increasing, and under a high-emissions scenario are expected to continue to increase until the end of the century to up to 4–5°C above their preindustrial levels (FAO/GIZ/ACSAD, 2017; UNESCWA et al., 2017).

Areas with highest vulnerability to climate change are in the Horn of Africa, the Sahel and the southwestern part of the Arabian Peninsula. These are adaptation hotspots, irrespective of the sector studied or the projected climate scenario, and they comprise several of the region's LDCs. While their exposure to climate change varies, they all exhibit low adaptive capacity. Even where areas are expected to witness increases in precipitation and moderate average temperature rises – as is the case in most of the Horn of Africa – low levels of adaptive capacity leave people highly vulnerable. Based on projected change in water availability and adaptive capacity, areas most vulnerable in relation to water are the upper Nile Valley, the southwestern part of the Arabian Peninsula and the northern part of the Horn of Africa (UNESCWA et al., 2017).

Intersecting with broad challenges of climate change and limited adaptive capacity are complex socio-economic and political dynamics, affecting water at the regional, national and subnational levels. Politicization and weaponization of water resources, displacement, and degradation of water infrastructure have been major challenges for countries affected by conflict (UNESCWA/IOM, 2017; UNESCWA, 2018). Inequalities in access to and control of water resources persist, especially across urban–rural and gender lines (UNESCWA/BGR, 2013; UNESCWA, 2018). Almost all Arab states are highly interdependent, as they often rely on shared, strategically important transboundary surface and groundwater resources. This compounds the challenges of achieving coherent, integrated water policy at the national level (UNESCWA et al., 2017).

The water-related impacts of climate change, exacerbated by these other water management challenges, threaten the achievement of numerous SDGs besides SDG 6. For example, the World Bank has identified Western Asia and North Africa as the regions facing the greatest economic threats from water scarcity exacerbated by climate change – costing up to 6% of gross domestic product by 2050 (SDG 8) (World Bank, 2016a). In the agriculture sector, over half the surface area of the Arab region's major cropland systems are in the two highest-vulnerability classes according to the RICCAR assessment, with the Nile valley, the southwestern part of the Arabian Peninsula, the Tigris-Euphrates basin and western parts of North Africa being the most vulnerable. The combined changes in temperature, precipitation and evapotranspiration will also threaten the food resource base for livestock, may induce the collapse of certain fish stocks, and could potentially reduce forest productivity (SDG 2) (FAO/GIZ/ACSAD, 2017). Changes in temperature could increase the risk of some water-related diseases, including diarrhoea and schistosomiasis. Where women and children bear the burden of water-related household tasks, gender-based vulnerabilities may also arise (SDG 3 and 5) (UNU-INWEH, 2017).

10.7.2 Policy responses: progress and challenges

A more in-depth assessment of three countries across the region – Jordan, Mauritania and Tunisia – shows a commitment to integrating water-related climate challenges in key strategy documents (Table 10.5). Jordan's national development plan recognizes water-related impacts of climate change as a threat to development, while its NDC stands out for including water-related mitigation actions, rather than treating water only as an adaptation issue. Mauritania's NDC prioritizes water-related adaptation actions and, as noted, its NAPA gives prominence to IWRM as an adaptation solution. Tunisia and Jordan's NDCs both mention water-related actions across other sectors, besides the water sector, implicitly acknowledging the contribution to other SDGs. However, the examples also point to certain gaps. In Tunisia and Mauritania's national development plans, the relevance of water management for addressing climate change is not mentioned. Despite the emphasis on IWRM and related institutional measures in Mauritania's NAPA, the NDC does not explicitly prioritize institutional strengthening for water management. The level of

IWRM implementation in all three countries suggests that significant action is needed to improve water management as a foundation for managing climate change impacts. Tunisia and Jordan's self-rated implementation progress scores 'medium high', and Mauritania's 'medium low' (UN Environment, 2018).

Beyond the national level, mention of transboundary water issues in a context of climate change is limited, despite their relevance for the countries considered. For example, in the Medjerda basin shared by Algeria and Tunisia, RICCAR modelling projects significantly drier conditions, with an increase in severe and extreme droughts in the high-emissions scenario. The Medjerda River contributes to the water supply of half the Tunisian population and underpins food security. Both countries meanwhile are grappling with the implications of utilizing this shared resource for development purposes, including plans for expanding hydropower, and dealing with already challenging issues of sedimentation and pollution. No adaptation plan would be entirely complete without building transboundary cooperation in the Medjerda basin.

The other two countries, however, have embarked on some regional projects that seek to harness the role of water as a 'climate connector'. One example is the Senegal River Basin Climate Change Resilience Development Project, which aims to strengthen transboundary management of water in the basin, including through climate change adaptation, across Guinea, Mali, Mauritania and Senegal. Another example seeks to address climate change-related water challenges facing displaced people in urban host settlements in Jordan, recognizing that water also acts as a 'climate connector' through human displacement (Table 10.5).

10.7.3 Opportunities to accelerate water–climate action at the national and regional scale

At the Regional Consultation on Climate Change for the 2019 Arab Forum for Sustainable Development (AFSD) and the High-Level Political Forum (HLPF) (UNESCWA, 2018), regional stakeholders identified many priorities and opportunities relating to water, including:

- **Sustainable urban development**, to ensure water supply, sanitation and wastewater treatment, and manage flood risk in a changing climate;
- **Enhancing data, research and innovation**, including seasonal and subseasonal climate predictions at the regional level, research on climate-adapted agriculture, and development and use of adaptation monitoring tools and metrics;
- **Increasing the resilience of vulnerable communities** exposed to floods and droughts, and threatened by food insecurity, including through the use of social protection mechanisms such as weather index insurance, and economic diversification;
- **Policy integration** between mitigation, adaptation and sustainable development, and between climate and the water–food–energy nexus; mainstreaming of climate change into national strategies, policies and programmes; and policy enforcement (e.g. for water efficiency policies); and
- **Increasing access to finance**, including via international climate funds and through the development of local markets and investment products, such as green *sukuk* bonds,[34] with appropriate capacity support for developing bankable projects.

Although these priorities point to the means of implementation, country stakeholders will need to seize windows of opportunity in the national political economy to convert them into action, starting in areas where the co-benefits of addressing water and climate together can be demonstrated relatively easily, and build a case that can convince others. On the investment theme, Jordan's experience in wastewater management offers an example, with impacts across many of the above priorities. In terms of increasing access to finance in order to address water-related climate change, Jordan's initiatives to attract blended finance for wastewater show how targeted public and international support can enable a return on investment for private investors in water reuse and efficiency projects.

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[34] A *sukuk* is an interest-free bond that generates returns to investors without infringing the principles of Islamic law (Shariah) (World Bank, 2019).

Table 10.5 Western Asia and North Africa country snapshot: how water-related climate change is addressed in strategy and implementation

Country	IWRM implementation score (UN Environment, 2018)	Scale	National Plan	NDC	Adaptation Plan	Examples of key regional/transboundary water–climate actions
Jordan	63 (Medium high)	National	Jordan 2025 recognizes the water supply–demand gap as a key challenge, which is exacerbated by climate change. Plans focus on developing new and alternative supplies and demand management, but do not mention climate change explicitly. Energy efficiency and renewables are mentioned as ways to reduce costs.	The NDC includes water-related mitigation actions, including energy efficiency and renewables in the water sector. Water adaptation actions include demand management and water resources monitoring. Water is also mentioned under agriculture and socio-economic adaptation actions.	Available information on the National Adaptation Plan (in development) indicates that a range of water-related climate change impacts will be considered, including desertification, water shortages, changes in rainfall intensity and droughts. Water will be one of six priority sectors addressed.	The Adaptation Fund project formulation grant, 'Increasing the Resilience of Displaced Persons to Climate Change-related Water Challenges in Urban Host Settlements', addresses water-related impacts of transboundary displacement.
		Transboundary	Not explicitly mentioned.	Not explicitly mentioned.	Full National Adaptation Plan not yet available.	
Mauritania	45 (Medium low)	National	Climate change has been identified as one of three key risks to the implementation of Mauritania's *Stratégie de Croissance Accélérée et de Prospérité Partagée, 2016-2030* (Strategy for Accelerated Growth and Shared Prosperity). It contains limited detail on climate change trends and projections, and on specific water-related projects and programmes, except in agriculture. The focus is on developing and rehabilitating irrigation infrastructure (Ministry of Economy and Finance of Mauritania, 2017).	Impacts on water resources are mentioned. Around half of the 19 adaptation activities in the NDC are water-related, including sanitation, resource mapping and remote monitoring, and infrastructure projects (built, e.g. desalination, water supply, and natural, e.g. wetland rehabilitation).	The National Programme of Adaptation to Climate Change (NAPA-RIM, 2004) highlights IWRM as an 'appropriate solution' to adapt to climate change. Priority adaptation activities in the water sector are detailed and relate to water resources knowledge, dissemination of drip irrigation, flood deceleration gates, installation and training in the use of electric pumps for irrigation, groundwater management, piezometric monitoring, and water quality monitoring (Islamic Republic of Mauritania, 2004).	The GEF-funded Senegal River Basin Climate Change Resilience Development Project, implemented by the World Bank and executed by OMVS, aims to strengthen transboundary water resources management in the basin through institutional strengthening, knowledge generation and dissemination, and piloting of progammes on climate change adaptation and integrated water management. It operates in Guinea, Mali, Mauritania and Senegal.
		Transboundary	There is some mention of the importance of the Senegal River and the Senegal River Basin Development Organization (OMVS) in relation to regional energy integration, fisheries and waterways, but not in relation to climate change adaptation/mitigation specifically.	Climate change has been recognized as an exacerbating challenge for fisheries on the Senegal River, but transboundary responses are not mentioned.	The Senegal River and the OMVS are mentioned briefly in relation to certain activities. No details are given on transboundary water management challenges or responses.	
Tunisia	55 (Medium high)	National	Climate change is recognized as an overarching challenge in *Le Plan de Développement 2016–2020* (Development Plan)*, but not specifically mentioned in water-related objectives, reforms and projects, which fall under a green economy heading.	Adaptation actions in water focus on transferring and reusing treated wastewater, and securing supply for large urban centres. Other water-related actions are listed under agriculture, ecosystems, health and tourism. The *Third National Communication* (2019) provides further details (Ministry of Local Affairs and Environment of Tunisia/GEF/UNDP, 2019).	The National Adaptation Plan is not yet available. The *Third National Communication* provides further details on water-related adaptation initiatives as well as various other sectors.	The project Regional Cooperation in the Water Sector in the Maghreb (CREM) is funded by BMZ and undertaken by GIZ with the Sahara and Sahel Observatory (OSS). It aims to improve water resource management in Algeria, Morocco and Tunisia through regional cooperation and information-sharing platforms. CREM has focused on water and climate change, including with a seminar on the topic in October 2019.
		Transboundary	Not explicitly mentioned.	Not explicitly mentioned.	National Adaptation Plan not yet available.	

* A summary French language version of Tunisia's development plan was reviewed (Le Plan de Développement 2016–2020) (Republic of Tunisia, 2016).

Source: Authors

The As-Samra Wastewater Treatment was initially designed in 2003 to treat wastewater for 2.3 million inhabitants of Amman and supply treated wastewater for irrigation to the surrounding region. Upgrading the plant became necessary, due to rapid population growth and an influx of refugees. This was completed in 2015, utilising US$223 million in blended finance sourced from the Government of Jordan (9%), the Millennium Challenge Corporation (MCC) (42%), and private debt and equity financing (49%). As well as providing international funding that addressed a 'viability gap' for private investors, MCC also acted as transaction advisors in preparing the project (World Bank, 2016c), again underscoring the importance of project preparation support from international or regional organizations. Existing water scarcity and population growth, rather than climate change, provided the original motive (World Bank, 2016c). However, in 2018, the European Bank for Reconstruction and Development (EBRD) and the EU agreed to support a further expansion in capacity, aiming for multiple co-benefits: increasing local communities' resilience, recovering energy from treated sludge and water flows (thus increasing energy security and climate change mitigation), and addressing additional needs created by the Syrian refugee crisis (Zgheib, 2018). Across the ESCWA countries, climate change could act as an additional motivator for blended finance to invest in water reuse and efficiency (especially where water scarcity is set to increase) and in energy recovery from wastewater.

Looking at opportunities at the regional level, the 2019 Regional Consultation Outcome Document (UNESCWA, 2018) emphasizes opportunities for regional climate outlook forums to strengthen the interaction between climate-sensitive sectors and climate information service providers. This speaks to the information theme, and RICCAR is itself a positive example cited in the Document. Though not mentioned in the Outcome Document, addressing water-related climate change impacts at the transboundary basin scale will be crucial for ESCWA countries, including with regards to the transboundary aquifers on which many are dependent (UNECE/UNESCO/UN-Water, 2018).

10.8

Conclusion: fostering water and climate action through regional learning and collaboration

This chapter reviewed the NDCs of 80 countries across the UN REC regions. Fifteen countries were analysed in greater depth, also covering national development strategies and adaptation plans. This analysis leads to clear implications for strategy formulation, and for closing the gap between strategy and implementation, with tasks falling to both national and regional-level stakeholders.

Three clear gaps emerge in the NDCs and other strategies considered – relatively easy wins for the next round of NDCs to address. Firstly, water-mediated climate risks and responses are too often framed as water sector issues, rather than cross-sectoral challenges that span across the SDGs – affecting areas such as agriculture, energy, health, industry, cities and ecosystems. Secondly, water's role in mitigation is overlooked, despite the need to manage water-related trade-offs in mitigation choices (for example in hydropower development), and exploit co-benefits, such as emissions reduction through wastewater treatment (via biogas), or water efficiency measures. The third and most important gap, from the regional perspective, is water's role as a climate connector, both in transboundary basins and in communities linked by shared climates. Migration, energy and food flows will also be importantly reshaped by the water-related impacts of climate change.

Beyond these gaps, other lessons point to the ways in which strategies can better lay the ground for leveraging the water–climate relationship *in practice* – i.e. with an eye to securing finance and moving to implementation. For example, some countries still need to resist the temptation to prioritize costly infrastructure in their NDCs as a means of attracting international climate finance, without the corresponding institutional strengthening and reform. Many countries could also make better use of existing water strategies when framing their climate strategies, given that climate invariably interacts with multiple drivers and stressors that water managers are already familiar with. Alternatives and complements to infrastructure and supply side measures, including demand management and NBS, should also feature more strongly in efforts to manage climate variability and change through water – not only in climate plans but also in land use, urban development and river basin plans (Browder et al., 2019). Finally, the precision and quality of project proposals in the water–climate space needs to improve if climate finance is to flow in the volumes needed to address the challenges ahead (see Chapter 12).

While the national level will continue to be instrumental in tackling climate change, regional approaches to support transformative shifts in implementation at the national level can play a critical role

Ensuring that water–climate action is appropriately framed in NDCs, NAPs, and in national economic and sectoral strategies is a critical first step, but the gap between strategy and implementation cannot be closed with words alone. The 2018 review of SDG Indicator 6.5.1 and 6.5.2 showed that many countries have struggled to implement IWRM (even under an implicit assumption of climate stationarity) and to establish agreements with their neighbours to govern management of transboundary basins. The urgency imposed by climate change increases the need to accelerate implementation on both counts – to avoid maladaptation and to tap into both mitigation and adaptation co-benefits.

While the national level will continue to be instrumental in tackling climate change, regional approaches to support transformative shifts in implementation at the national level can play a critical role. Three areas emerge as important: improving collaboration and coordination between responsible **institutions**; ensuring that action is based on sound **information** and evidence; and increasing access to both public and private finance for climate-resilient **investment**.

On **institutions**, climate change has been shown to offer an entry point for regional dialogue and cooperation on water, whether at the project or strategy level (e.g. in the Chu-Talas, Mekong, Niger, Volta and Victoria basins) or, at its most powerful, in catalysing establishment of broader transboundary agreements and institutions, as in the Dniester basin.

Regional organizations have an obvious role here to commission and disseminate **knowledge and information** on climate and water. The RICCAR and CR4D initiatives highlighted in this chapter also point to the benefits of involving scientists and promoting uptake of information by key decision-makers from the outset, to ensure efforts are grounded in national and regional decision-making contexts, and to ensure water-related climate information is actually used. Collaboration on information-sharing has long provided an important anchor for broader collaboration on transboundary issues – as for example between Bangladesh and India on flooding – and climate change is likely to increase the imperative for this.

In terms of **investment**, regional cooperation on water-related climate change is especially important as it can create opportunities for economies of scale, especially where it taps into common political and economic priorities. CRIDF in southern Africa deliberately targets climate–water initiatives in transboundary basins to allow for this, helping countries with project preparation and identifying viable funding options. Transboundary basins offer a natural unit to encourage cooperation between wealthier and poorer basin states, as in the Danube, potentially facilitating flows of investment as well as technical assistance. A strong interface between regional and national levels is, again, vital. The sovereign disaster insurance mechanism established by the ARC shows how regional initiatives for facilitating financing are most effective when they are well linked to national systems – in this case, social protection systems that can route insurance payouts to drought-affected communities. Finally, besides facilitating access to and providing international climate finance, regional and international organizations can help countries make fiscal reforms and improve their creditworthiness, improving the domestic environment for financing climate-resilient water infrastructure – as shown by the World Bank and IMF's Climate Change Policy Assessments.

Just as the submission of new and updated NDCs by individual countries offers a window of opportunity at the national level, there are specific entry points for regional-level action in all of these three areas. One is the UN development system reform and its reflections at the regional level, which are ongoing and aim for a more coherent and better-coordinated utilization of regional capacities and resources in support of national priorities (ECOSOC, 2018). Other entry points are the regional fora and negotiating groups within international climate negotiations and processes, such as the UNFCCC regional climate weeks held annually in Africa, Latin America and the Caribbean, and Asia and the Pacific, which could highlight the role of water as a regional climate – and development – connector (UN-Water, 2019).

Without a significant expansion of regional approaches to tackling climate-related water challenges, the interlinked goals of the Paris Agreement, the Sendai Framework and the 2030 Agenda will not be achieved.

11

Water governance for resilience to climate change

Global Youth Climate Strike in March 2019 in Sydney (Australia).

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This chapter outlines legal, institutional and political means to support climate change adaptation and mitigation, to enhance resilience, and to reduce vulnerability through more inclusive water management, especially at the country level.

11.1 Introduction

This chapter argues for the importance of good governance and more just and inclusive water resources management under the mounting pressures from climate change. As droughts are prolonged and water becomes scarcer, technical fixes and supply augmentation may not prove sufficient. Instead, more efficient use (and reuse) of water and more equitable processes for sharing the benefits of its use need to be fostered through participatory, just and transparent approaches. The chapter emphasizes the importance of:

- Political will, leadership and action – which may be mounting in the area of climate, not least thanks to agency by the world's youth.
- The cross-cutting nature of water and climate through the entire economy. Trade-offs and conflicting interests need to be addressed at all levels to negotiate solutions across sectors. Policy integration and coordination may need to be centrally placed.
- Participation and transparency can help inclusiveness and legitimacy in decision-making by way of allowing different perspectives to be brought to bear. Broader agreements enable the necessary buy-in for more effective implementation and collective action towards desired goals.
- Poverty and inequality exacerbate vulnerability to shocks and stressors, including climate-related water crises. Greater equality in water/climate action (and more generally) not only helps alleviate poverty, but also builds resilience to the effects of climate change as well as every-day crises.

11.2 Integrating climate change concerns in water management

Climate change adaptation and mitigation need to deal with increasingly complex interactions between energy, land, water and biodiversity (IPCC, 2014d), adding additional complexity to the realm of water resources management. Ameliorating the effects of climate change through water management also involves politics, since there are many trade-offs and often conflicting interests regarding resource management.

11.2.1 Integrated and inclusiveness in water governance

Climate change adaptation and mitigation, like water management, are about action on the ground. The quality and direction of action is shaped by social rules and relations, also known as the governance framework. Water governance determines "*who gets water, when, and how much*" (UNDP-SIWI WGF, 2015, p. 4; Iza and Stein, 2009).

It has long been clear that governments alone are not able to take on the full responsibility of 'providing' water services to all, especially in low-income settings (Franks and Cleaver, 2007; Jiménez and Pérez-Foguet, 2010), and that a broader 'whole-of-society' approach is required. While governments are the main drivers of policy-setting and regulation, the actual provision of water services is increasingly carried out by non-state actors (Finger and Allouche, 2002; Kjellén, 2006). This trend has motivated the use of the term 'governance' rather than 'government.'

Climate policies, traditionally overseen by environment ministries which often have limited power, are increasingly moving towards more central and influential locations

Increasing competition over water resources also reinforces the importance of governance in water management and reuse (Niasse, 2017). With increasing competition and resulting pressure on water resources, the way that water is allocated in society warrants 'renegotiation.' According to Hall et al. (2014), adapting to hydrologic variability involves matters of institutions, infrastructure and information. Institutions are needed to undertake the planning and development of legal and economic instruments to manage and share risks.

The management of both climate and water requires mechanisms for oversight and coordination. It is important, though by no means easy, for such bodies to keep the overview to ensure necessary integration of issues and coordination between actors. Sectoral fragmentation and bureaucratic competition may pose serious challenges for the integration across scales (Koch et al., 2006; Lebel et al., 2011). This calls for 1) greater public participation to discuss and manage climate risk; 2) building adaptive capacities at multiple levels (see e.g. Cap-Net UNDP/UNITAR/REDICA/WMO/UN Environment-DHI/IHE-Delft, 2018); and 3) prioritizing risk reduction for socially vulnerable groups (see final section of this chapter) (Tompkins and Adger, 2005; Oliveira, 2009; Lebel et al., 2011; Ayers et al., 2014; Coirolo and Rahman, 2014).

For national and local authorities, to manage water resources in a way that fosters resilience to climate change, it is essential to improve governance. Good governance involves adhering to principles of human rights, including effectiveness, responsiveness and accountability; openness and transparency; participation in the performance of key governance functions relating to policy and institutional arrangements; planning and coordination; and regulation and licensing (UNECE, 1998; OECD, 2015). For the integration of substance, integrated water resources management (IWRM) provides a process for involving stakeholders across society, the economy and the environment (Cap-Net UNDP/UNITAR/REDICA/WMO/UN Environment-DHI/IHE-Delft, 2018).

11.2.2 Integrated water resources management for climate resilience

The call for IWRM in the 2030 Agenda, Sustainable Development Goal (SDG) Target 6.5, is a recognition of how water cuts across all sectors of society. With increasing competition for available water, and the additional unpredictability and variability brought on by climate change, the IWRM process for water allocation and use efficiency becomes more acute than ever. Yet, there is no magical solution and sectoral fragmentation is not easy to overcome (Smith and Jønch Clausen, n.d.). Fully in line with the broader societal trend from governments (alone) towards governance (including all sectors of society), IWRM builds on multi-stakeholder processes. This brings a diversity of perspectives, as well as improved and innovative ideas and coping strategies, although it does not necessarily address power imbalances between different interests. Participation of stakeholders is a human rights obligation, and can also enhance legitimacy of the process and the resulting choices (Saravanan et al., 2009; Schoeman et al., 2014). Gender mainstreaming – an integral part of IWRM – also stands to improve IWRM processes and outcomes. As stated below, climate processes also increasingly rely on the involvement of and claims from youth.

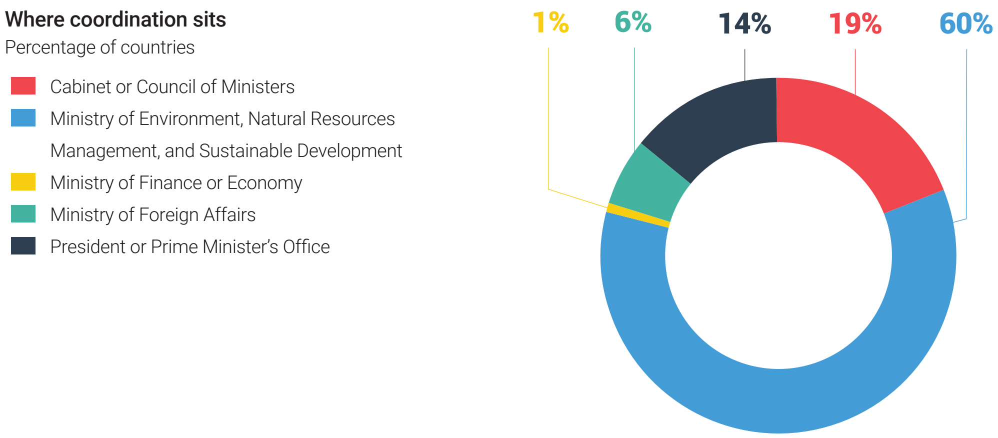
Butterworth et al. (2010) suggest that practical problem-solving can be a useful entry point for IWRM. With more engagement of non-water professionals (decision-makers outside the water sector), the potential for fruitfully engaging around climate change mitigation and adaptation increases (Smith and Jønch Clausen, 2018; n.d.). Transboundary cooperation also helps to share costs and benefits of adaptation and to increase the overall efficiency and effectiveness of adaptation in a basin (UNECE/INBO, 2015).

11.2.3 Linking water policy and climate change at the country level

The nationally determined contributions (NDCs) are at the heart of the Paris Agreement as the means for achieving its long-term goals (see Section 2.1.2). The NDCs embody efforts by each country to reduce emissions and to adapt to the impacts of climate change. All Parties are requested to submit the next round of NDCs (new, updated or enhanced) by 2020 and every five years thereafter.

In 2019, a joint analysis by the United Nations Development Programme (UNDP) and the United Nations Framework Convention for Climate Change (UNFCCC) gauged country progress in establishing the governance architectures needed for the successful implementation of climate change mitigation and adaptation measures. Almost 90% of countries surveyed had a coordination mechanism in place. In 80% of the countries, a *governance* mechanism was in place to coordinate and engage non-governmental parts of society. Moreover, climate policies, traditionally overseen by environment ministries which often have limited power, are increasingly moving towards more central and influential locations. Whereas 60% of coordination to guide NDC implementation remains with environment or natural resources management ministries, over a third of the countries surveyed had NDC implementation coordinated by either the Cabinet or the Office of the President or Prime Minister (UNDP/UNFCCC, 2019) (Figure 11.1).

Figure 11.1 Location of coordination mechanism for NDC implementation



Source: UNDP/UNFCCC (2019, p. 27).

The UNFCCC's 2016 synthesis of the aggregate effect of 161 intended nationally determined contributions (INDCs)[35] highlighted the link between climate change and development priorities. This includes "*adaptation measures with mitigation co-benefits*" on integrated water resources management, such as watershed protection, waste- and stormwater management, water conservation, recycling and desalination (UNFCCC, 2016, p. 75), with water emerging as a leading domain for adaptation action (see Figure 2.3). With various types of action related to the protection of water resources included in the adaptation components, this speaks for 'water security' as a key development priority for most Parties (UNFCCC, 2016).

While two-thirds of countries outline a general portfolio of water projects in their INDCs, only one in ten cites what could be called a detailed project proposal, and these originated either from domestic water planning processes or had emerged from previous climate funding proposals (Hedger and Nakhooda, 2015). A recent survey of the NDCs of 80 countries from a water perspective found that over 70% of the individual water actions planned for adaptation involved some form of management or governance instrument, while 63% noted the need for general water resources management (GWP, 2018b) (Figure 11.2). The report also found that 'no-regret' options – measures that make sense in their own right regardless of future weather patterns, could be explored further.

More generally, for countries to implement internationally agreed commitments, it is critical to adopt or update national law to align with international commitments (Burchi, 2019). Domestic regulation of water resources development, use, conservation and protection forms the foundational pillar of water governance and is the prime instrument for the implementation of NDCs under the Paris Agreement.

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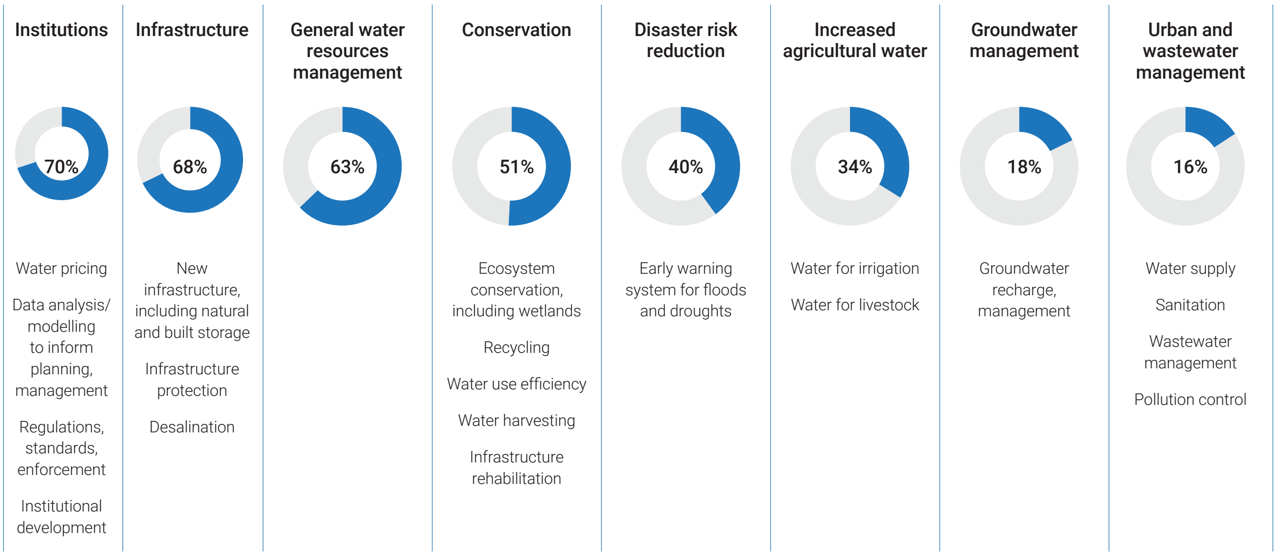
[35] The intended nationally determined contributions (INDCs) were converted to NDCs upon ratification of the Paris Agreement.

Figure 11.2 Prioritized water actions for adaptation in NDCs



Source: GWP (2018b, fig. 4, p. 5).

The concrete steps to realize the mitigation and adaptation objectives of the NDCs are indicated through Nationally Appropriate Mitigation Actions (NAMAs) and National Adaptation Plans (NAPs). The NAP process helps countries, essentially the least developed ones (LDCs), to elaborate medium- and long-term climate adaptation plans, beyond the more immediate or short-term National Adaptation Programmes of Action (NAPAs). With an emphasis on the bottom-up approach, some countries take this to the local level in developing their Local Adaptation Plan of Action (LAPA) (Dazé et al., 2016). For example, Bhutan has combined local water security with long-term planning for climate change adaptation (Box 11.1).

The NAPA stepwise process, as outlined in the manual for climate change adaptation and IWRM (Cap-Net UNDP/UNITAR/REDICA/WMO/UN Environment-DHI/IHE-Delft, 2018), takes existing coping strategies at the grassroots level into account and builds on them to identify priority activities, rather than focusing on scenario-based modelling to assess future vulnerability and long-term policy at state level. NAPAs should also include short profiles of projects or activities intended to address the most urgent and immediate adaptation needs of the LDC Parties to the Climate Framework Convention (McGray et al., 2007).

The longer-term planning through the NAPs is supported through the recently updated NAP Water Supplement. This considers water as a means to an end: a critical input to economic development, livelihood security and environmental sustainability. It considers water resources broadly, to include water supply along with all water-related sectors such as agriculture, energy, transport, public health and disaster risk management (GWP, 2019b). Over 90 developing countries are at various stages of preparing NAPs and 13 have formally submitted theirs (UNDP/UNFCCC, 2019). UNFCCC (n.d.b) suggests that the NAP process should be "*continuous, progressive and iterative*" and follow a "*country-driven, gender-sensitive, participatory and fully transparent approach.*"

11.3 Public participation in agenda-setting, decision-making and monitoring

Climate change fundamentally alters the way in which water must be managed. Traditionally, water managers have made predictions about future water availability based on historical water trends, but as warming temperatures affect all aspects of the hydrologic cycle (Rodell et al., 2018), historical baselines are in many cases no longer a reliable indicator of water availability (Milly et al., 2008).

Box 11.1 National Adaptation Programme of Action for local water security in Bhutan

The vulnerabilities and challenges faced by local communities in Bhutan are further exacerbated by climate-induced threats, ranging from flash floods and landslides to forest fires and seasonal water shortages. Due to traditional gender roles, the burden of water becoming scarcer and more difficult to access falls disproportionately on women.

Photo: © Sonam Phuntsho/UNDP Bhutan (2018).

With the objective of finding sustainable solutions, the Government of Bhutan, with support from the United Nations Development Programme (UNDP), developed and revised the country's National Adaptation Programme of Action to incorporate new emerging hazards. With funding from the Global Environment Facility-Least Developed Countries Fund (GEF-LDCF), climate change adaptation projects have enabled local/indigenous communities to build resilience. Improved access to running water and the construction of concrete-based water storage units have enhanced water security. The formation of water user groups has also increased communities' capacity to protect water sources, while at the same time enhancing community bonding.

Bhutan is prioritizing long-term planning for climate change adaptation with the goal of building a stronger evidence and a stronger investment case for scaling up adaptation.

Source: Extracted from Phuntsho et al. (2019).

Even with increasingly sophisticated models, climate impacts cannot be confidently predicted at the river basin, lake or aquifer scale. This new level or depth of uncertainty underscores that planning cannot be treated as a technical fix or as an equation to be resolved. Indeed, water governance research has highlighted the important role of participation to address complex water issues (Von Korff et al., 2010; Bryson et al., 2012; Kirschke and Newig, 2017). As highlighted above, the paradigm shift from government to governance takes decision-making out of the sole hands of experts in water or natural resources management. Linking environmental and human rights, Principle 10 of the *Rio Declaration on Environment and Development* (UNGA, 1992) stresses the need for citizen participation in environmental issues. This principle sets out three fundamental rights: access to information, access to public participation and access to justice, as key pillars of sound environmental governance.

Apart from the scientific base that all approaches for managing risks and ecosystems should have, resilient water management and IWRM are also firmly rooted in the multi-stakeholder approach, involving citizens, the private sector and civil society in the process of water governance (Saravanan et al., 2009; Schoeman et al., 2014). Greater public participation to manage climate risk is suggested as a way to build adaptive capacities at multiple levels, avoid institutional traps and prioritize risk reduction for socially vulnerable groups (Tompkins and Adger, 2005; Oliveira, 2009; Lebel et al., 2011; Ayers et al., 2014; Coirolo and Rahman, 2014). This requires the incorporation of a bottom-up approach in river basin planning processes to ensure the incorporation of communities' diverse views on climate risk and adaptation, and to the links to income generation and livelihoods. At the same time, scientific information and data also need to be made available at the local level and included as information into local multi-stakeholder decision processes.

New means of communication facilitated by information technology and social media have enabled citizens to collect and hold information (see Chapter 13), acting as watchdogs towards their decision-makers. This relatively new channel of communication has also enabled 'citizen science' with knowledge generation and sharing. Citizen science generally refers to the involvement of citizens in scientific projects, mostly in the generation of data (Conrad and Hilchey, 2011; Jollymore et al., 2017). Recent examples involve on-farm crop variety evaluation using crowdsourced citizen science, assigning small experimental tasks to volunteering farmers across the world (Van Etten et al., 2019), or using cellphones to maintain information about water points location, functionality and quality. However, gathering scientifically sound water quality data is a challenging process, requiring requisite funding, training, motivation and feedback to citizens (Conrad and Hilchey, 2011; Jollymore et al., 2017; Kim et al., 2018).

While governments remain responsible for leading national climate mitigation and adaptation measures as well as water governance, the process of change is always coproduced. In line with the concept of governance, those leading or spurring action, the 'agents of change', may come from many different places – they may be within government or in other sectors. The following section highlights initiatives by a diverse set of groupings, like youth, cities, private sector and indigenous peoples, which in different ways can help drive or coproduce the process towards climate change adaptation or mitigation, sometimes as forerunners.

11.3.1 Agents of change

There are many indications that young people are increasingly concerned about climate change. As actions are taking place all over the world to initiate policy change and push for action, the younger generations are beginning to change the narrative. In March 2019, the Global Youth Climate Strike was carried out by students across the globe who, mobilized through social media, were skipping classes to protest against governments' inaction to address global warming. The protests were among the largest international actions yet, involving around 1.4 million students and young adults in more than 120 countries (Leach, 2019), pushing decision-makers to react. During the UN Climate Action Summit in September 2019, youth and adults left schools and workplaces in over 150 countries to join the 'Fridays for Future school strikes manifestation. Initiated by Greta Thunberg,[36] a Swedish teenager, the movement became global. For example, during the Africa Climate Week in Accra, in March 2019, several youth groups, drawn from across Africa, under the leadership of the Ghana Youth Environment Movement, peacefully marched through the streets to the conference centre where government leaders and policy-makers were engaged in discussions. The youth's message on placards was simple: there have been so many talks already and the time for climate change action is now.

Youth are also mobilized and supported by several water-focused networks, such as the World Youth Parliament for Water, the Water Youth Network and Young Water Solutions. Many try to pair local initiatives with raising awareness and policy recommendations.

Cities have also become forerunners of climate action in many countries. There are several networks or initiatives that spur their members to act, like Local Governments for Sustainability (ICLEI), the C40 network of megacities committed to addressing climate change, and the 100 Resilient Cities, pioneered by the Rockefeller Foundation. A major share of the action seems to be underpinned by improved knowledge: a review of over 2,000 watersheds and 530 cities by McDonald and Shemie (2014) found that cities that had conducted water risk assessments were considerably more likely to take action, with the most common type of action being to reduce leakage in the water supply. This is echoed by the recent ranking of leading cities in terms of environmental action by Carbon Disclosure Project-Disclosure Insight Action (CDP, n.d.). Examples of action include fixing water leaks to tackle drought, which was the focus of Taipei, the Taiwan province of China (Scott, 2019). As climate change reveals underlying threats to urban water, it urges cities to undertake this kind of no-regret measures (Kjellén, 2019).

Also, leading companies have made commitments to reduce their water footprint and greenhouse gas (GHG) emissions in order to address their contribution to water stress and climate change (see Chapter 7). With regards to companies' handling of water, the CDP *Global Water Report 2018* found that despite a greater

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[36] *"For more than 30 years the science has been crystal clear. How dare you continue to look away, and come here saying that you are doing enough, when the politics and solutions needed are still nowhere in sight… And if you choose to fail us I say we will never forgive you. We will not let you get away with this. Right here, right now is where we draw the line. The world is waking up. And change is coming, whether you like it or not."* – Greta Thunberg, speaking at the 2019 UN Climate Action Summit (Thunberg, 2019).

awareness of water risks and targets to reduce water withdrawals, self-reported withdrawals have increased significantly in recent years, especially among food, beverage, agriculture, manufacturing and mineral extraction companies in Asia and Latin America (CDP, 2018).

In the United Kingdom (UK), water companies, regulators, academics and non-governmental organizations have worked together to create a long-term planning framework for water resources. Looking 50 years ahead, the study's results suggested that England and Wales may face longer, more frequent and more acute droughts than previously thought. This study has led to a more strategic approach to securing water supplies by balancing enhanced supply infrastructure and demand management (Water UK, 2016).

While most sectors of society need to reorient themselves in the face of climate change, indigenous peoples, who have often lived in marginal and challenging environments, already implement what could be termed both mitigation and adaptation strategies as part of ancestral or traditional natural resources management. These include traditional responses to drought and other disasters, or carbon fixation (e.g. preservation of forests) (Kelles-Viitanen, 2018). Chanza and De Wit (2016) and many others suggest that indigenous knowledge needs to be much more effectively drawn into climate governance.

11.3.2 Decision-making under uncertainty

‘Adaptive management’ is a structured process of decision-making in the face of uncertainty, aiming to manage uncertainty in natural resource and ecosystem management (Holling, 1978; Allen and Stankey, 2009). It is increasingly applied to water resources management (Pahl-Wostl et al., 2010; Schoeman et al., 2014). While governance and decision-making under conditions of uncertainty are not new, climate change presents a new spectrum of uncertainties: ‘deep uncertainty’ rather than ‘known risks’ (World Bank, 2016a). Maintaining flexibility in governance arrangements and frameworks over time is critical to coping with high levels of climate uncertainty.

One way to deal with uncertainty is to prioritize ‘no-regret’ measures in the application of policies and to take actions that make sense in their own rights. This includes efficiency-increasing measures like repairing leaks in urban systems and ensuring that water in irrigation systems actually reach the crop. Such measures help reduce waste and save resources, irrespective of climate change or future weather patterns.

‘Bottom-up’ risk assessment approaches constitute a new generation of methodologies for addressing decision-making under uncertainty. They are designed to ensure robust, context-specific and flexible decision-making in water management (Brown et al., 2011; Wilby, 2011; Haasnoot et al., 2015). They place a strong emphasis on avoiding chronic failure of the system’s performance (Mendoza et al., 2018). Early stakeholder involvement is essential for finding more comprehensive solutions and policy responses, which are ultimately easier to implement and better received (OECD, 2015), ensuring that local contexts are fully incorporated into the process. One example is the stepwise Climate Risk Informed Decision Analysis (CRIDA) (Figure 11.3) (Mendoza et al., 2018).

Data integration and analysis are important and need to be strengthened in order to help reduce the risks and impacts of water-related disasters, including floods, landslides and droughts, the prediction of which rely greatly on science and technology for early warnings. Further, hydrological data need to be integrated with social and economic analyses, since behaviour and resilience depend greatly on who has access and control over different resources (2030 WRG/UNDP, 2019).

An example of transdisciplinary approaches connecting science and technology with society is the establishment of the Platform on Water Resilience and Disasters, a worldwide project promoted by the International Flood Initiative.[37] Further efforts at enhancing accessibility of water-related societal information is the UN-Water SDG 6 data portal[38] and the Aqueduct Water Risk Atlas,[39] a global water risk mapping tool that helps companies, investors, governments and other users understand where and how water risks and opportunities are emerging worldwide.

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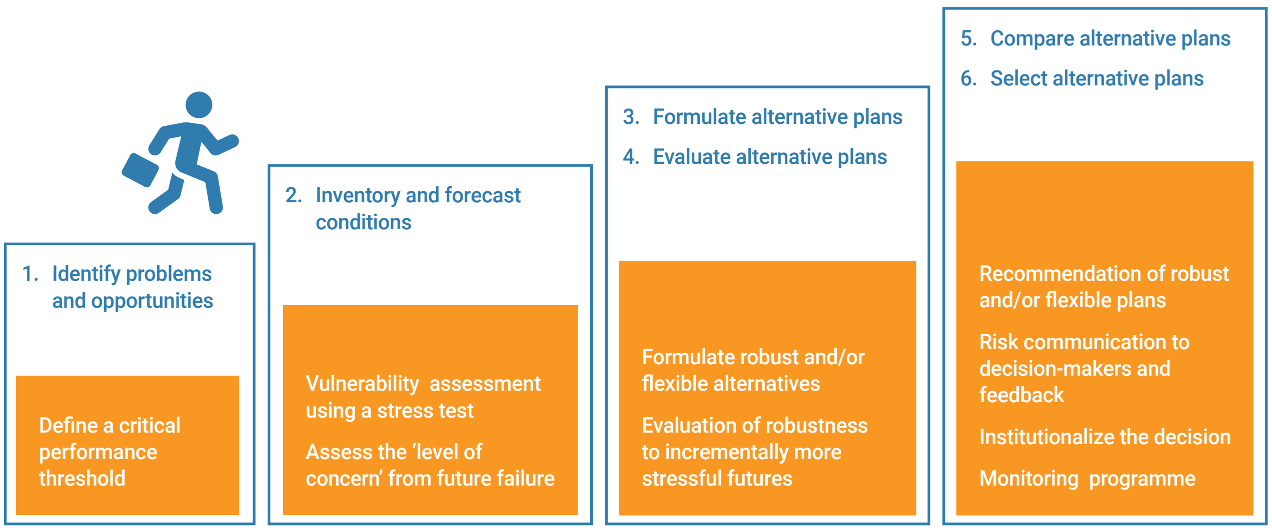
[37] www.ifi-home.info.

[38] www.sdg6data.org/.

[39] www.wri.org/our-work/project/aqueduct/about.

Figure 11.3 Climate Risk Informed Decision Analysis tasks within a typical planning framework



Note: Blue boxes show widespread planning framework steps; orange boxes show CRIDA steps.

Source: Mendoza et al. (2018, fig. 01, p. 30).

11.4 Reducing vulnerability and enhancing resilience by combatting poverty and inequality

Climate change impacts countries and local populations differently, depending on their wealth, social status and other factors affecting their ability to adapt (Eakin and Luers, 2006; UNDP, 2019). Strategies need to distinguish between different social groups and strata, and give specific attention to those already marginalized (Mobjörk et al., 2016). In fact, sudden or gradual crisis events tend to reinforce already existing vulnerabilities, exposure and inequalities (Schaar, 2018).

Poverty, discrimination and vulnerability are closely related and typically intersect. Women and girls from minority ethnic groups, remote or disadvantaged areas may suffer multiple forms of exclusion and oppression. When disasters hit, such inequalities can become exacerbated and poor people are more likely to be affected. Poor people are also more likely to lose relatively more than the non-poor (Hallegatte et al., 2016),[40] as gender and power dimensions affect disaster responses. For example, gender-perspective studies from Bhutan found that women are often not reached by early warning systems, in part due to cultural norms that restrict their freedom of movement and autonomous decision-making, having to wait for men's permission before evacuating (Shrestha et al., 2016; Davison, 2017). In other settings, successful evacuation may be affected by matters like having access to a vehicle.

Indigenous peoples' cultural and geographical existence across periods and throughout colonization often places them in antagonistic situations with dominant political and economic actors and the mainstream of society and politics (WWAP, 2019). This history can induce discrimination. Indigenous peoples are often overlooked in water allocation decisions and may be marginalized in conventional water management systems and disproportionately affected by water conflicts (Barber and Jackson, 2014). Indigenous peoples often share strong cultural ties with their ecosystems and depend for their livelihoods on renewable natural resources that are endangered by climate variability and extremes (ILO, 2017).

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[40] Hallegatte et al. (2016) found that factors like low literacy rates, high dependency ratios and weak housing structures increase the vulnerability of people affected by drought in rural India, while factors like access to social networks and basic services such as water and sanitation, health, and education would play a significant role in reducing such vulnerability.

Box 11.2 Watershed management as part of disaster risk reduction – Restoring the basin slopes of Gonaïves, Haiti

In the aftermath of Hurricane Jeanne, in 2004, the International Labour Organization (ILO), the United Nations Development Programme (UNDP) and the World Food Programme (WFP) worked closely with the Government of Haiti on a job creation programme in Gonaïves. The programme created jobs through environment protection activities. Social dialogue and development of institutional capacity of local and community actors contributed to lessening the effects of land erosion and high demographic pressure on the environment.

Over 50,000 households benefited from labour-intensive activities like setting up tree nurseries, building anti-erosive ditches and reinforcing bridges. Concretely, 210,000 tree seedlings were planted on slopes and 630,000 grass seedlings were planted in anti-erosion ditches.

The project demonstrated that the use of local resource-based techniques and community contracting could prevent the further deterioration of eroded catchments. The community contracting also helped clarify roles and responsibilities, establish technical capacities for broader environmental protection, and promote cooperation among workers, local organizations and their federations, local authorities, and regional technical departments.

Contributed by ILO.

Adopting a human rights-based approach (HRBA) to development can also help achieve climate justice in relation to water. Such approaches are at the core of good governance, providing concerned stakeholders with opportunities to voice their interests and to influence the agenda and the outcomes of the discussions. The HRBA provides mechanisms to ensure that all people are brought into the communication process and can participate in collectively addressing the root causes of vulnerability (Cap-Net UNDP/WaterLex/UNDP-SIWI GWF/Radica, 2017; Cap-Net UNDP/UNITAR/REDICA/WMO/UN Environment-DHI/IHE-Delft; 2018). Development, water management and vulnerability to climate change are all linked, and "*prudent water-management policies can do much to secure growth, making people richer and thus more resilient to climate stresses*" (World Bank, 2016a, p. 14). Wealth creation among those who need it can help reduce overall vulnerability in society, including water-related effects of climate change.

Poor people's assets, for example their house, animals or crops, are less resistant to the effects of disaster. Further, they may represent the totality of a poor household's wealth, since poor households are less likely to have financial savings or access to credit. These differences in exposure and vulnerability make natural disasters increase inequality and may contribute to a detrimental decoupling of economic growth and poverty reduction (Hallegatte et al., 2016). Poor people are disproportionately at risk from environmental change, as they tend to be more directly dependent on ecosystems, relying for example on rainfed agriculture or the gathering of wild plants and animals (McGranahan et al., 1999). Unless such socio-economic circumstances be fully considered, adaptation policies stand to become considerably less effective.

An important consideration in reducing vulnerability to climate-induced water-related hazards is to view risks, challenges, exposure and vulnerabilities in their totality. Wisner et al. (2003, p. 4) criticizes the "*artificial separation*" between the risk from natural hazards and the many dangers inherent in 'normal' life. In this vein, the PBL Netherlands Environmental Assessment Agency (2018) reminds us of the difference in magnitude of the impacts from different types of disasters and the everyday effects of inadequate access to water and sanitation. Everyday exposure to inadequate water and sanitation kills magnitudes more people – mainly children – than conflicts, earthquakes and epidemics combined. This speaks for the importance of combining development and humanitarian work, for example by joining livelihoods and disaster risk prevention pursuits, as illustrated in Box 11.2.

Water governance has an important role in enhancing climate resilience through poverty alleviation. Water policies that provide greater access to water for the use of poor people help reduce not only poverty and inequality, but also vulnerability, by increasing resilience to climate change. Such 'no-regret' measures may be fostered by an inclusive approach to climate and water management, allowing the voices of disadvantaged groups to influence the agenda and decisions. Political will and determination are critical to make things happen. Participation and transparency are crucial for ensuring that actions proceed in the right direction and contribute to agreed goals.

12

Climate finance: Financial and economic considerations

Aerial view of sewage plant treatment in Wrocław (Poland).

World Bank | Shanna Edberg and Diego Juan Rodriguez

With contributions from: Francesca Bernardini, Sonja Koeppel and Hanna Plotnykova (UNECE); Chiara Christina Colombo and Danielle Gaillard-Picher (WWC); Todd Gartner (WRI); Amarnath Giriraj (IWMI); Merylyn Hedger (ODI); Marianne Kjellén (UNDP); John Matthews and Alex Mauroner (AGWA); and Lesley Pories (Water.org)

This chapter addresses the current state of water and climate finance, the costs of inaction versus the benefits of action, and several ways to access climate finance flows to improve water management as well as water supply and sanitation services, while synergistically mitigating and/or adapting to climate change.

12.1 Overview

Water resources management is currently underfinanced and in need of greater attention from governments. Climate change, as described in earlier chapters, threatens water resources management, increases the risk of weather-related events, and affects the availability and quality of water and sanitation services around the world. However, it also presents an opportunity: to leverage climate finance mechanisms to provide additional funding to improve water management, and by doing so improve safe water and sanitation access through actions that also mitigate and/or increase resilience to climate change, often providing other co-benefits at the same time.

Water resources management is currently underfinanced and in need of greater attention from governments

The growing amount of global attention being paid to climate change offers an unprecedented opportunity to put water in the spotlight of sustainable development financing efforts. Connecting water to climate change could allow the international community to leverage additional resources to address the wide overlap between climate and water challenges, and thus improve the outlook of meeting the overall water management goals as outlined in Sustainable Development Goal (SDG) 6.

12.2 Why connect water and climate finance

12.2.1 The state of water financing

Current levels of financing are inadequate to reach the international community's goal of universal availability and sustainable management of water and sanitation, as embodied in SDG 6. In order to meet the first two targets of SDG 6 – access to safe water, sanitation and hygiene (WASH) services for all by 2030 – capital investments must reach US$114 billion per year. This is about three times the current annual capital investment levels in WASH. In addition to the initial capital inflows, significant resources are required to operate and maintain water and sanitation infrastructure and sustain universal coverage. These costs are recurrent and will outweigh the capital costs by 1.4 to 1.6 times by 2029 (Hutton and Varughese, 2016).

The above expenditures do not include the costlier Targets 6.3 through 6.6 of SDG 6, which include improving water quality, increasing the proportion of treated wastewater, increasing water efficiency, implementing integrated water resources management, and protecting and restoring water-related ecosystems. It also does not explicitly include climate-resilient technologies. Thus, without significantly increasing the levels of investment in water, it will be "*nearly impossible*" to reach SDG 6 (Fonseca and Pories, 2017, p. 8).

12.2.2 Preventive action saves

Maintaining business as usual – that is, ignoring climate risks and failing to increase water investments – would clearly threaten the chances of meeting SDG 6, and would have wider reverberations as well. Since water is a critical factor of production in many sectors, increasing scarcity and vulnerability of water supplies would threaten livelihoods around the globe. Water-related losses could send some regions "*into sustained negative growth,*" with growth rates in some regions at risk of declining by 6% of gross domestic product by 2050 (World Bank, 2016a, p. vi). These changes will burden poor households the most.

Thus, when considering the cost of financing water infrastructure, it is also necessary to evaluate "*the counterfactual risk of not financing infrastructure*" (WWC, 2018, p. 15). Preventive action therefore could have a positive return on investments in the form of avoided future losses (Box 12.1) while also improving current water management practices. But for this to happen, water managers will need to properly incorporate planning and investment design in the analytical methods that allow for the proper identification of climatic and non-climatic risks and uncertainties. It is therefore essential to prioritize adaptation strategies and investments that can manage those risks and uncertainties.

Proponents of water projects could aim to increase the water sector's share of climate finance and emphasize water's ties to other climate-related sectors in order to ensure greater funding for water management

12.2.3 Connecting water to climate finance

If current water financing is inadequate, and increasing water financing offers considerable potential benefits, then what can be done to increase access to financing and realize those benefits? While water management requires more attention from traditional sources such as government and development finance, the answer may also lie in adding climate finance. The Climate Policy Initiative (CPI) reports that climate finance has been increasing in recent years, from US$360 billion in 2012 to an estimated US$510–530 billion in 2017. Out of the US$455 billion invested in 2016, US$11 billion went to water and wastewater management in climate adaptation, and US$0.7 billion to water and wastewater management in climate mitigation. This means only 2.6% of 2016's climate finance went directly to water management, even if this may mask water-related projects in other sectors, such as disaster risk management; agriculture, forestry, land use, and natural resource management; coastal protection; and other sectors (CPI, 2018). Proponents of water projects could aim to increase the water sector's share of climate finance and emphasize water's ties to other climate-related sectors in order to ensure greater funding for water management.

12.2.4 Mitigation versus adaptation financing

Two promising trends will increasingly help water projects access climate finance. The first is the increasing recognition of the mitigation potential within water and sanitation projects. This trend could be particularly advantageous, as mitigation made up 93.8% of climate financing in 2016, but water

Box 12.1 Avoided flood losses in Mexico

An example of the losses that can be avoided by preventive action comes from the Mexican state of Tabasco. In a large flood event in 2007, the State suffered significant damages and losses amounting to US$2.9 billion. This flood event led the Federal and State Governments to design an Integrated Hydraulic Plan. The aim of the Plan was to implement a set of solutions that guaranteed the safety of the population, the non-interruption of economic activities, and the stability of ecosystems in the occurrence of flood events. The structural investments (embankments, reinforcements) and non-structural investments (development of early warning systems, risk maps, capacity building) amounted to approximately US$750 million, and the Plan was implemented between 2008 and 2010. Three years after the 2007 floods, Tabasco was flooded at an even greater magnitude than before. But this time, the measures taken by the Integrated Hydraulic Plan drastically reduced the level of damages and losses of the State. The 2010 damages and losses were in the order of US$585 million, 80% less than in 2007. The benefit of the disaster risk reduction measures implemented in 2010 was three times higher than their cost.

Source: World Bank (2017d).

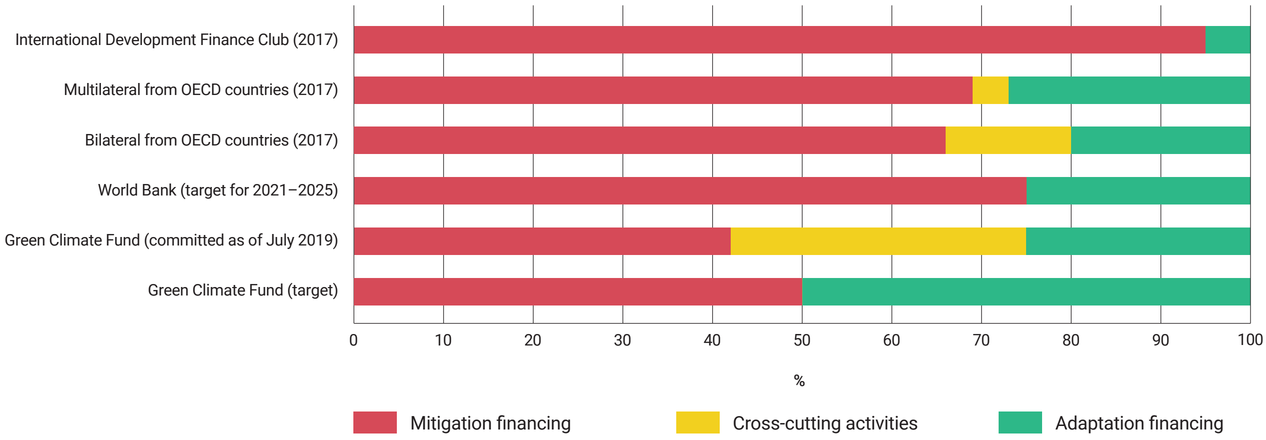
projects consisted of a fraction of 1% of that sum (CPI, 2018). There may be a large untapped potential in intentionally linking water and mitigation, attracting increased financing to water management goals. Increasingly, however, the mitigation potential of water management options is being recognized.

Water and wastewater utilities can have large energy footprints, so there is significant mitigation potential in increasing both water and energy efficiency, as well as in recovering energy, water and nutrients from wastewater streams (Box 12.2; see also Chapters 3 and 9). Other solutions with benefits in both water and climate include regenerative agriculture, green infrastructure, ecosystem restoration and other innovative initiatives such as 'floatovoltaics' – solar panels that float on reservoirs and provide clean energy while preventing water loss through evaporation.

The second trend is an increasing emphasis on financing climate adaptation. Climate finance is typically heavily weighted toward mitigation rather than adaptation, but recently this has begun to change (Figure 12.1). The Green Climate Fund (see section 12.5.1) has a target of financing 50% mitigation and 50% adaptation, the World Bank has dedicated US$50 billion to adaptation over the next five years, and the criteria for certifying climate bonds include resilience investments (Tall and Brandon, 2019). With these developments, water practitioners who integrate climate change analysis into their project planning will increase their chances of accessing climate finance, be it for mitigation or adaptation.

Disaster risk management made up a little less than 14% of 2016's climate financing for adaptation, about US$3 billion (CPI, 2018).

Figure 12.1 Ratio of mitigation to adaptation financing, by source



Source: Authors, based on data from World Bank (2018b), IDFC (2018), OECD (2018) and Green Climate Fund (n.d.).

12.3 Economic considerations of water and climate projects

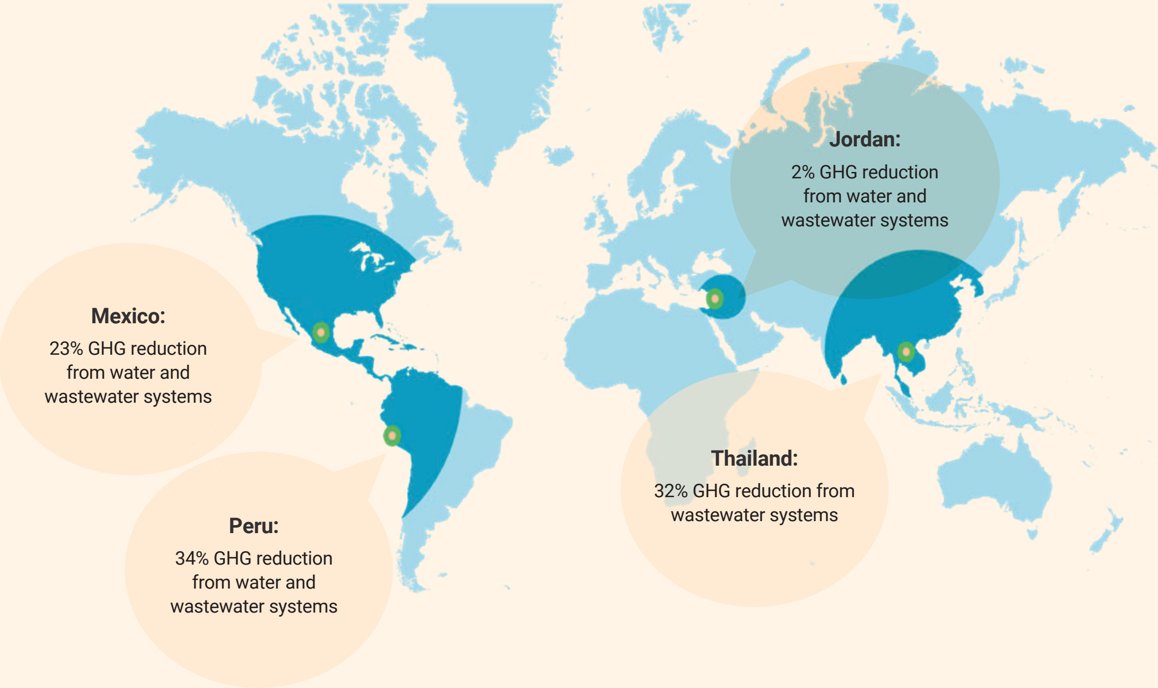
12.3.1 The value of water

Water is immensely valuable. The value of access to safe water and to sanitation and hygiene services goes well beyond the price paid at the tap, and is a vital input to thriving economies, stable communities and healthy populations. Water is essential to human survival, a necessary component of food and energy production, and both an input to and a recipient of the ecosystem services that sustain all life on Earth. For these reasons, "*water is the common currency which links nearly every SDG*" (World Bank, 2016a, p. vi). Given the increased scarcity and variability caused by climate change, "*water management will be crucial in determining whether the world achieves the Sustainable Development Goals*" (World Bank, 2016a, p. vi). Water also has intangible social, cultural and religious worth, and it is invaluable for human dignity. It is an entitlement of all people.

Box 12.2 Mitigation in water and wastewater

The project Water and Wastewater Companies for Climate Mitigation (WaCCliM), financed by the German Government and implemented by The German Agency for International Cooperation GmbH (GIZ) and the International Water Association (IWA), introduces greenhouse gas (GHG) reduction technologies at utilities in Jordan, Mexico, Peru and Thailand. These measures include energy consumption reduction, energy and nutrient recovery, water reuse, and water loss reduction. The project also developed the Energy Performance and Carbon Emissions Assessment and Monitoring (ECAM) tool to help water and wastewater utilities assess GHG emissions and mitigation opportunities, and aids countries in improving the regulatory, institutional and financial framework for integrating emissions reductions into the water supply and sanitation sector. These measures have allowed the affected utilities to reduce thousands of tonnes of CO_2e emissions while also producing financial savings and improving the quality of service.

Figure Estimated greenhouse gas reductions in WaCCliM pilots by 2018



Sources: WaCCliM (2017a; 2017b).

There are ongoing efforts to measure the value of water. The High-Level Panel on Water released *Principles on Valuing Water* with guidance for allocating, managing and pricing water services considering the many different dimensions of value that water holds (HLPW, 2018b). Valuation of water, along with strengthening governance and institutional capacity, is one of the most critical steps toward sustainable development of water resources (Garrick et al., 2017).

There is no single value of water, nor even one single way to measure its value. But several projects and modelling efforts illustrate the substantial benefits of improving water management in the context of climate change. For example, the World Bank estimates that improving water resource management could accelerate growth in some regions of the world by 6% (World Bank, 2016a). Various water-related climate adaptation policies can also provide co-benefits such as job creation, improved public health, promotion of gender equality, reduced household expenses and carbon sequestration, among others.

12.3.2 Water project bankability

Although climate finance is increasing, demand for it is also increasing, and current levels are not yet adequate to meet the need. Accessing climate finance can be competitive and difficult, especially for complex water projects that may transcend national boundaries. Practitioners must ensure that a project is 'bankable', or likely to receive funding based on the project's design, objectives, risk profile, enabling environment and other factors. Bankable climate projects are those that have a "*clearly articulated link to climate change impacts, familiarity and strict compliance with funding procedures,*" and sometimes additional funding sources (World Bank, 2019, p. 11).

A project's bankability for climate finance differs slightly from its bankability for development finance in general. Projects hoping to use climate finance must explicitly address the causes and/or consequences of climate change to be considered bankable. Adaptation and resilience projects must also demonstrate how the project will respond to and address expected climate impacts in the project's area. These links must be backed with scientific evidence, such as climate data. Climate financers such as the Green Climate Fund also require all projects to address the gender dimensions of climate change and to mainstream gender equality considerations into the project cycle. As with development financing, all projects must respect human rights, including the right to participation.

Furthermore, to increase chances of accessing climate financing, project proponents should search for the most compatible financing sources and match their project plan to the financer's criteria and objectives. Project proposals should align with related policies and plans already in place, such as national development strategies, National Adaptation Plans, or river basin investment and management plans. Projects that communicate and address risks, and projects that capture co-benefits in other areas such as health, are also considered more bankable.

Project developers must take the time to form relationships, gain insight into the climate financing landscape and advocate for the benefits of their approach

Basin organizations have an important role to play in transboundary basins as they can bring added benefits while implementing multi-country projects. However, many basins organizations struggle in accessing funds for climate change adaptation from different sources (UNECE/INBO, 2015). Understanding and managing the special risks and complexities of transboundary river basin projects are critical to preparing bankable project proposals that will attract public and private financing partners. The example of the Niger basin (Box 12.3) demonstrates that pooling projects, a rigorous scientific and planning process, and early involvement of stakeholders and donors have enabled river basin organizations to raise significant funds for climate change adaptation (World Bank, 2019).

Thinking about water projects in terms of their bankability to climate financers can help align climate and water goals and ameliorate project funding gaps. It is important to note, however, that a bankable project will not necessarily attract climate financing simply because it is a good project. Project developers must take the time to form relationships, gain insight into the climate financing landscape and advocate for the benefits of their approach.

Box 12.3 Pooling projects in African transboundary basins

The Niger basin counts nine riparian countries and is home to 112 million people who rely heavily on the natural resources it provides. Those nine countries and the Niger Basin Authority will prepare and implement the Investment Plan for the Strengthening of Resilience to Climate Change, which includes investments "*targeting vulnerability to water stress, variability, soil, land, and ecosystem degradation, and strengthening resilience.*" These measures were taken from the Niger Basin Authority's Operational Plan, countries' National Adaptation Plans and National Adaptation Programmes of Action, and country proposals. The Plan is expected to cost US$3.11 billion and will be financed by the Niger Basin Authority member countries, the World Bank, the African Development Bank and private sources.

Pooling projects is a way to avoid maladaptation and the negative consequences that could result from considering only one fragment of an interconnected basin ecosystem. It can also promote resource efficiency and cost-effectiveness. For example, reforestation efforts upstream can improve water quality and reduce erosion and flood risk downstream.

Source: World Bank (2019, p. 25).

12.3.3 Pro-poor climate–water finance strategies

People living in poverty are the most vulnerable to the impacts of climate change and water insecurity. Therefore, differentiated strategies that specifically consider the resilience needs of marginalized groups must be built into larger water–climate plans and projects. People who live below the poverty line and have low financial reserves are the least prepared to adapt to intense climate events such as flash floods or prolonged droughts. Comprehensive climate plans, particularly those discussed later in this chapter, that incorporate national mitigation and adaptation efforts alongside more specific water management projects need to incorporate financing structures that can assist at-risk populations to recover from these intense climate events. In addition, access to finance can be a critical component of mitigation and adaptation strategies, allowing low-income people to invest in climate-resilient technologies like rainwater harvesting.

12.4 Types of climate investments for water projects

12.4.1 No-regret and low-regret investments

Climate impacts are not always certain, especially at the micro-level. Scientific knowledge and predictive climate modelling continue to improve, but decisions must be made in the meantime to help communities prepare and adapt. No-regret and low-regret investments are a response to this uncertainty.

No-regret investments are investments that are beneficial regardless of the climate impacts – they would provide benefits even in the absence of climate change, as well as across a range of potential climate hazards. Low-regret investments "*may incur an additional cost to offset climate change risks, but these costs are small in comparison to the benefits of avoiding future costs*" (GWP-Caribbean/CCCCC, 2014, p. 1). Such projects increase resilience. They also tend to bring co-benefits to multiple sectors and stakeholders, have built-in flexibility for future adjustments, and minimize trade-offs.

No-regret interventions for water and climate change could include rainwater harvesting, sustainable groundwater management, micro-irrigation technologies, wastewater reuse and improved water storage (Vermeulen et al., 2013). Any intervention that improves efficiency and conservation, by reducing leaks for example, is also generally considered a low- or no-regret choice. These interventions also tie into both mitigation and adaptation, since efficiency and conservation both reduce energy use and increase water availability.

12.4.2 Results-based climate financing

Results-based climate financing is a type of investment in which "*funds are disbursed by an investor or donor to a recipient upon the achievement of a pre-agreed set of* [mitigation or adaptation] *results, with achievement of these results being subject to independent verification*" (World Bank, 2017d, p. 1). It can be used on its own or together with upfront financing, and it can be deployed at different scales and with different project entities.

There are several different ways to approach results-based climate financing, but as a modality it has the potential to improve monitoring, reporting and verification capacity, strengthen domestic institutions, mobilize the private sector, and create or strengthen markets to produce climate results. Most results-based investments thus far have been made in climate mitigation projects, since carbon emissions are a well-defined and measurable indicator, but this type of financing can also be used for climate adaptation goals. In this regard, new results-based climate mechanisms can target nature-based solutions (NBS), where the funding gap is expected to be the greatest (WWC/GWP, 2018). Projects that find synergies between water management goals and climate mitigation or adaptation can take advantage of this promising financing modality.

12.5 Using multilateral climate finance for water

Three multilateral funding institutions exist specifically for financing climate and environmental projects: The Green Climate Fund, the Global Environment Facility and the Adaptation Fund. In addition, development banks have begun to prioritize climate change and integrate it into their development activities, and some have climate-specific funds. Water managers could look to these funds, which in 2016 provided US$51 billion, or 11% of all climate financing (CPI, 2018).

12.5.1 The Green Climate Fund

The Green Climate Fund was established as a financing mechanism of the Paris Agreement, to help developing countries mitigate and adapt to climate change. As of 2019, it has received US$10.3 billion in pledges, out of the goal of US$100 billion per year, and the Fund has committed about US$5 billion of that to approved climate projects (Box 12.4). Though most if not all their results areas and investment priorities involve water management, the clearest result area for water is health, food and water security, which falls under adaptation (Green Climate Fund, n.d.).

12.5.2 The Global Environment Facility

The Global Environment Facility provides grants for several types of environmental projects, including climate change mitigation and adaptation. It also serves as the financial mechanism for the United Nations Framework Convention on Climate Change (UNFCCC). Since its founding in 1992, it has funded almost 1,000 climate mitigation projects and 330 adaptation projects. A recent project with both climate and water benefits "*helped generate tools to assess the effects of glacier retreat and integrate climate change considerations into strategic planning*", and "*addressed pressing development issues related to water supply or irrigation in Bolivia, Ecuador and Peru*" (GEF, n.d.).

12.5.3 The Adaptation Fund

The Adaptation Fund was originally set up under the Kyoto Protocol and finances projects that help developing countries adapt to climate change. It has supported over 80 adaptation projects since 2010 and has committed US$564 million to climate adaptation and resilience activities (Adaptation Fund, 2019). During the 24th United Nations Climate Change Conference (COP24) in December 2018, country Parties decided that the Adaptation Fund would serve the Paris Agreement starting in 2019. Water management is one of the Adaptation Fund's project sectors, and it accepts transboundary project proposals.

Several multilateral development banks have formulated guidelines to mainstream climate analysis into planning and investment design

12.5.4 Development banks

Climate change is a threat to development and anti-poverty goals, while acting on climate can bring development and equity co-benefits. For those reasons, at COP24 the World Bank committed to doubling its climate investments to US$200 billion from 2021–2025 to support countries taking ambitious climate action (World Bank, 2018b). Of that sum, US$50 billion will be dedicated to adaptation finance. The World Bank aligns its internal processes and metrics to consider climate risks and opportunities, and evaluates its operations for climate impacts and co-benefits. So, it is worthwhile for water managers hoping to access World Bank funds to mainstream climate mitigation and/or adaptation into their plans (World Bank/IFC/MIGA, 2016).

Box 12.4 The Green Climate Fund and water management in Sri Lanka

A Green Climate Fund project in Sri Lanka will upgrade village irrigation systems in vulnerable communities and promote climate-smart farming practices in three river basins. It will also enhance climate-resilient water supply management and strengthen climate and hydrological forecasting to enhance water management and adaptive capacity. The climate-smart agriculture component provides both climate adaptation and mitigation benefits, while also conserving water and protecting drinking water sources.

Source: Green Climate Fund (2018).

Several multilateral development banks have formulated guidelines to mainstream climate analysis into planning and investment design. Furthermore, over the past few years, multilateral development banks have also formulated guidance notes to help operational teams move towards climate-smart portfolios of investments and to maximize the climate adaptation and mitigation results of each investment.

Regional development banks also have climate change initiatives that water practitioners could tap into. The members of the International Development Finance Club, a global network of 23 national and regional development banks, committed US$196 billion to climate finance in 2017, primarily for climate mitigation. Of the US$10 billion allocated to climate adaptation, 58% went to water 'preservation', which includes catchment management, rainwater harvesting, and rehabbing water distribution networks. The International Development Club's provided 72% of its green finance commitments (including climate and other environmental financing) to the East Asia and Pacific region, while the European Union (EU) received 14% of green finance, and Latin America and the Caribbean received 6%. Green financing commitments to Eastern Europe and Central Asia, the Middle East and North Africa, South Asia, and Sub-Saharan Africa were smaller, at 1–3% per region (IDFC, 2018).

12.6 Using national climate finance for water

12.6.1 Bilateral climate finance

Climate financing initiatives or development agencies with climate objectives exist in many countries and regions, including the EU, Germany (Box 12.5), Japan, the Nordic countries, Switzerland, the United Kingdom, The United Arab Emirates, the United States of America and others. There are also regional and national climate funds in developing countries, such as the Amazon Fund, the Bangladesh Climate Change Trust Fund, the Green Fund in South Africa, and the Southern Africa Trust (ACT Alliance, 2018).

Bilateral public climate finance from developed to developing countries grew overall from US$22.5 billion in 2013 to US$27 billion in 2017 (OECD, 2018). As is the trend with most climate financers, bilateral sources primarily financed mitigation (66% of bilateral finance in 2017) over adaptation (21%), with cross-cutting activities more common among bilateral sources (14% in 2017) than multilateral ones (4%) (OECD, 2018).

12.6.2 National and subnational climate finance

As each country's nationally determined contribution (NDC) to the Paris Agreement becomes mainstreamed into government spending plans, domestic expenditures by national governments may be a growing source of climate finance. The UNFCCC estimates that US$232 billion of domestic public finance was spent per year in 2015 and 2016, with US$157 billion per year in developing countries and US$75 billion in developed countries. However, "*comprehensive data on domestic climate expenditures are not readily available, nor are such data collected regularly or using a consistent methodology*" (UNFCCC, 2018, p. 62). If water managers can align their projects to their country's NDCs, they may be able to access these domestic sources of climate financing. But without comprehensive data, it is difficult to draw conclusions that could guide water and sanitation financing efforts.

Box 12.5 Bilateral climate finance for water management in Nepal, Peru and Uganda

An example of water sector involvement in a bilateral climate project took place in Nepal, Peru and Uganda between 2011 and 2016. The Global Ecosystems Based Adaptation in Mountains Programme was funded by the German Government's International Climate Initiative and implemented by the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP) and the International Union for the Conservation of Nature and Natural Resources (IUCN), with local government partners. The programme's activities included ecosystem restoration and management, soil nutrient management, water conservation and management, and irrigation measures. These measures helped secure water supplies and build resilience to droughts in the three project areas, among other benefits.

Source: UNDP (2015).

National domestic finance institutions may also offer climate financing. In Latin America and the Caribbean, national development banks such as the Brazilian Development Bank "*are already the single largest source of public climate finance in domestic markets*" (NRDC, 2017, p. 4).

Several countries and subnational jurisdictions have begun establishing green investment banks, also known as green banks, in recent years. Green banks "*are publicly capitalized, domestically focused, specialist financial institutions specifically established to crowd in private capital*" to climate and environmental investments (NRDC, 2017, p. 1). While green banks were initially established almost exclusively in OECD countries, current efforts are expanding the model to countries in Africa, Asia and Latin America (Green Bank Network, 2018). As green banks begin to proliferate, water project managers may wish to monitor this area for future financing opportunities.

12.7 Alternative finance sources

12.7.1 Private sector finance

Private sector finance accounted for a majority (54%, or US$230 billion) of climate finance flows in 2016, the bulk of which came from project developers (CPI, 2018). Other sources of private finance could include carbon markets, foreign direct investment, insurance, or commercial financial institutions. An estimated US$15.7 billion of private financing was mobilized by multilateral development banks (UNFCCC, 2018). But the sources and destinations of private financing are not well documented.

One emerging source of private financing that may be useful to water practitioners is the green bond market. Pioneered in 2007, green bonds and climate bonds offer "*significant global opportunities to mobilize capital at scale for low carbon, climate resilient infrastructure and development efforts*" (World Bank, 2018c). The green bond market has grown rapidly, from US$3.4 billion in 2012 to US$168 billion in 2018. The Climate Bonds Standard, a labelling scheme akin to FairTrade certification, has released Water Infrastructure Criteria (Box 12.6) to certify water-related bonds for low-carbon and climate-resilient water management standards (Climate Bonds Initiative, 2018).

In 2018, the Global Green Bond Partnership was launched to accelerate the issuance of green bonds. The Partnership plans to develop toolkits for companies, subnational entities and other groups that are interested in issuing green bonds, so water managers can take advantage of those resource as they come out (World Bank, 2018c). There are also other types of environmental bonds emerging, such as catastrophe bonds, environmental impact bonds and resilience bonds.

Box 12.6 Water infrastructure criteria for climate bonds

Certification for the water infrastructure criteria under the Climate Bonds Standard is based on two components:

1. Mitigation: Greenhouse gas emissions from water projects do not increase and comply with business-as-usual baselines or aim at emissions reduction to be delivered over the operational lifetime of the water asset or project.
2. Adaptation and resilience: Water infrastructure and its surrounding ecosystem are resilient to climate change and have sufficient adaptation to address climate change risks. To demonstrate that, issuers must address the following:
    a. Allocation: How water is shared by users within a given basin or aquifer;
    b. Governance: How/whether water will be formally negotiated and governed;
    c. Technical diagnostics: How/whether changes to the hydrologic system are addressed over time;
    d. For nature-based and hybrid infrastructure only: Whether issuers have sufficient understanding of ecological impacts at/beyond project site with ongoing monitoring and management capacity;
    e. Assessment of the Adaptation Plan: Checking the completeness of the coping mechanisms to address identified climate vulnerabilities.

Source: Excerpt from Climate Bonds Initiative (2017, p. 1).

Aerial view of the Changi Water Reclamation Plant (Singapore).

12.7.2 Public-private partnerships

Climate-smart public–private partnerships are another potential way to meet financing needs for climate-resilient water infrastructure investment. The Public–Private Infrastructure Advisory Facility (PPIAF) has defined climate change as a strategic priority for fiscal years 2018–2022. The Facility will focus on climate change initiatives and embed climate activities in its technical assistance and knowledge work (Suriyagoda, 2017). The PPIAF Climate Change Trust Fund for Infrastructure will promote climate-smart models and enabling environments for climate-smart public–private partnerships. Water supply and sanitation is one of the sectors included in the Fund's planned programmatic initiatives.

While climate change does not currently play a significant role in public–private partnerships, the World Bank and PPIAF's mainstreaming of climate change into their initiatives and knowledge activities will define future infrastructure trends and is another area for water managers to watch.

12.7.3 Blended finance

Blended finance "*incorporates different types of financing into a single project or fund*" (World Bank, 2019, p. 24). Blended finance can have a crowding-in effect by using concessional loans (i.e. loans with below-market rates) or grants to make projects more attractive for traditional sources of capital, and it can help project proponents better manage risks. Several development banks, climate funds and bilateral funds have begun using this paradigm to attract commercial finance and support projects that have a potentially high impact but must overcome barriers to be commercially viable.

The bankability criteria of the Green Climate Fund and other prominent sources of climate financing tend to screen out smaller-scale, subnational-level projects. To address this financing gap, R20 Regions of Climate Action and BlueOrchard Finance are, as of early 2019, in the process of setting up a Subnational Climate Fund for Africa. The Fund will leverage blended finance to fund subnational infrastructure projects with positive climate impacts in emerging markets (R20 for Climate Action, 2018). For water project developers, especially in Africa, this may be a financing source to watch for future opportunities.

Special attention must be paid to low-income countries, because "*countries that have the greatest need for investment are often perceived as risky and as having governance issues*". Only 3.6% of the private finance mobilized by using blended finance in 2012–2015 flowed to low-income countries (Hedger, 2018b, p. 6).

12.8 Conclusion

Growing interest in climate finance, as well as its variety of sources, instruments and destinations, make it an attractive opportunity for water project proponents and organizations hoping to reach SDG 6. The challenge lies in their ability to establish the water–climate connection and access this finance.

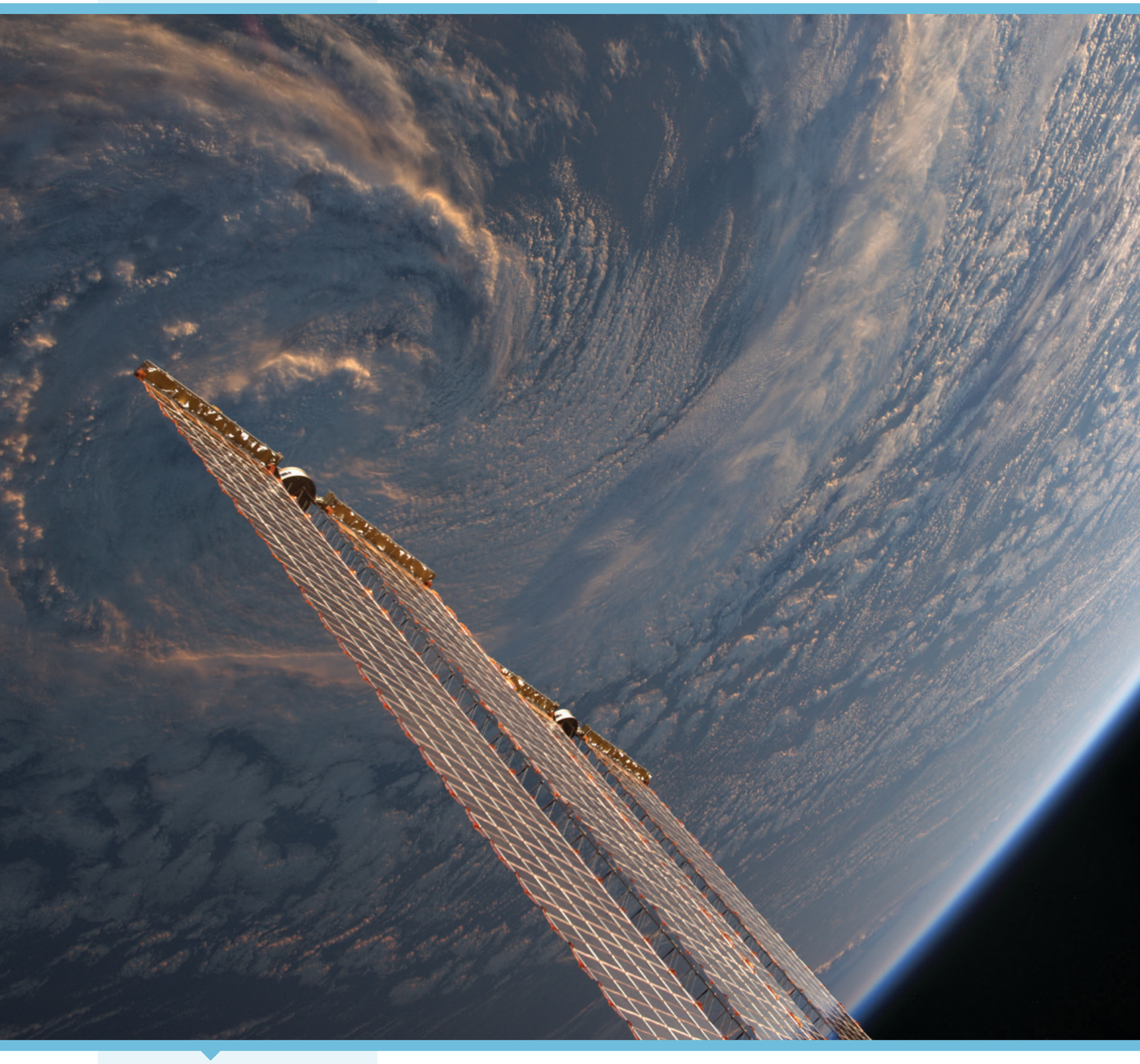
Since most climate financers primarily fund mitigation activities, finding alignment between water development goals and climate mitigation may offer more immediate opportunities for future funding than adaptation activities. Up until now, the connection between water management and adaptation has been more apparent and more readily developed than mitigation. However, the mitigation potential of various water management interventions is increasingly being recognized. Policy and technical solutions that align water management goals and climate mitigation goals should be a growing topic for research and knowledge sharing, to help both climate and water practitioners take advantage of these connections.

Climate finance architecture is complex and evolving. There are multiple mechanisms, institutions, programmes and activities at various scales. For this reason, increasing coordination among these actors would minimize duplication and inefficiencies as well as facilitate access to funding. Potential sources of growth in climate finance will be national institutions hoping to finance their NDCs and the Green Climate Fund with its push to reach US$100 billion in financing per year. Green banks, green bonds, subnational climate funds and public–private partnerships are other emerging areas to watch for future climate financing opportunities.

It must be stated, however, that water management and climate action are both underfinanced. Although it is increasing, climate financing is not as abundant as needed to address climate change (CPI, 2018). Competition for climate financing is high, as there is not enough to go around. Therefore, to meet both climate and water goals, it may not be enough to encourage water–climate synergies and help water developers access climate finance. Structural changes may also be needed, such as giving water a higher priority within climate funds, designing linking mechanisms between the water and climate communities, and identifying strategies to bring blended finance to the countries with the greatest need. Water practitioners could become climate advocates as well, encouraging greater funding for addressing climate change. Since water links all the SDGs and climate change threatens them, it is critical to plan and invest in sustainable water management that properly incorporates climate resilience and robustness against multiple futures.

13

Technological innovation and citizen knowledge



A storm at dusk.

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This chapter highlights the challenges and opportunities in promoting research, innovation and science to support informed decision-making.

13.1 Introduction

Climate change questions our ability, as societies, to predict, anticipate and absorb perturbations. In other words, it challenges us to develop mechanisms for reducing uncertainty, mitigating risk and improving resilience, in order to adapt to a changing environment. As described in previous chapters, improved water management offers several opportunities in terms of both climate change adaptation and mitigation. The challenges, in terms of technological innovation, knowledge management, research and capacity development, are to promote the generation of new tools and approaches through advanced research and development, and, equally as important, to accelerate the implementation of existing knowledge and technologies across all countries and regions. However, these actions alone will not lead to expected outcomes unless they are also accompanied by awareness-raising, as well as educational and capacity development programmes aimed at widely disseminating this knowledge and stimulating the uptake of new and existing technologies. Access to knowledge and information is essential, and all persons have a right to benefit from science and its applications (UNGA, 1966, Article 15).

Various adaptation and mitigation measures have the potential to foster water management systems' resilience to climate change and to enhance water security, contributing directly to sustainable development. Such measures can only be effective and durable if they strengthen the knowledge interface on climate and water systems and services, and identify needs, practices, priorities, challenges and gaps. Policy-makers and scientists are faced with the challenge of evaluating and measuring change and its potential consequences. Uncertainty about the extent of the impacts of climate change on water resources management and societies in general can hamper the ability to successfully implement adaptation measures into national development and into environmental protection plans and policies. Another challenge derives from the fact that adaptation and mitigation require interdisciplinary, cross-sectoral and multidimensional approaches, which in turn require the setting-up of a shared framework. Multidisciplinary approaches, tools and methodologies are therefore necessary.

Science, technology and innovation have proven to be key drivers of economic and social development, transforming water resources governance and management at an unprecedented pace. The integration of science, technology and innovation policies into water resources development strategies, as well as its combination with institutional and organizational changes, can valuably contribute to raising efficiency, improving resilience, and fostering the transition to sustainability within and beyond the water sector. Such achievements offer new opportunities and responses to support sound decision-making in the governance and management of water resources while minimizing the impact of climate change. Innovation provides more affordable and efficient technological tools, enables their implementation, and is indeed central to translating water-related scientific knowledge and technological know-how into useful processes, services and employment.

13.2 Technological innovation

Science, technologies and innovation are rapidly evolving and continue to support a number of water resources management activities, including i) overall assessment and monitoring of water resources and hydrological processes; ii) conservation, recovery and reuse of water resources; iii) adaptation of infrastructures; iv) cost reduction in treatment and distribution processes; v) efficiency of water supply delivery and use; and vi) access to safe drinking water and sanitation. Several innovations in the water sector have over the past years deepened our understanding of climate-related challenges, and provided new ways to adapt in a flexible way to climate change and to mitigate greenhouse gas (GHG) emissions. Some of these innovations are listed in this section.

Earth observation and space technologies generate data and information on weather, climate and the evolution of water resources at various levels. Satellite-based earth observation can help identify trends in precipitation, evapotranspiration, snow and ice cover/melting, as well as runoff and storage. For example, information on changes in land water storage, including in aquifers, is obtained through an analysis of gravity variation by the Gravity Recovery and Climate Experiment (GRACE) satellite mission operated by the US National Aeronautics and Space Administration (NASA) and the German Aerospace Center (DLR). Since its launch in 2002, GRACE recorded a threefold increase of the mass of ice lost in the polar and mountainous regions. It also observed that of the 37 largest land-based aquifers, 13 have undergone critical mass loss, which has been induced both by climate-related change and anthropogenic pressure (Tapley et al., 2019).

Advances in satellite technologies over the past decades have also helped improve the understanding of climate change impacts on water quality by monitoring river, marine and coastal ecosystems with high levels of accuracy (Skoulikaris et al., 2018). For instance, satellite monitoring of environmental parameters such as turbidity, suspended solids, Chlorophyll-a, dissolved organic matters and water surface temperature helps identify areas potentially affected by eutrophication and algal blooms (UNESCO-IHP, 2018).

Remote sensing conducted through satellites can also be a powerful tool for monitoring. While it can reveal large-scale processes and features that are not easily observable via traditional methods, the temporal and spatial resolution may not be fully adequate for smaller-scale applications and data analysis. However, when backed with national statistics, field-based observations and numerical simulation models, remote sensing can contribute to a comprehensive assessment of climate change impacts related to water and thus support decision-making with regard to potential adaptation responses.

> *Evolutions in the field of data acquisition have been facilitated by high-speed internet networks and global coverage, as well as cloud computing and the enhancement of virtual storage capabilities*

Advanced sensor technologies can support smart water management, notably by enabling online and real-time monitoring of water availability and quality. Wireless sensors for monitoring water consumption have been developed and are increasingly used in combination to allow for remote water metering. In Alicante, Spain, the smart metering of water consumption data has helped meeting supply and end-use information needs, contributing to the city's sustainable urban water management objectives (March et al., 2017). Water quality monitoring at different stages of wastewater treatment processes is essential for ensuring its safe reuse for various purposes, thus helping to reduce overall water stress (see Box 3.2). Such monitoring is also vital for detecting chemical leakages or pollution spills in a timely manner, as well as for analysing the effectiveness of decontamination measures.

Major **information and communication technologies** (ICT) evolutions in the field of data acquisition have been facilitated by high-speed internet networks and global coverage, as well as cloud computing and the enhancement of virtual storage capabilities (i.e. cloud backup and storage services with multiple functions) (Skoulikaris et al., 2018). New technologies such as Internet-of-things (IoT), big data, Artificial intelligence (AI) and machine learning are also emerging, with diverse applications in reducing uncertainty, mitigating risk and improving resilience to climate change.

The IoT designates a computing concept in which every-day physical objects are connected to the internet and/or to each other, forming a network of interrelated devices that can communicate and transfer data without requiring human intervention. As water loss management is becoming increasingly important with more and more water stress-affected regions, the IoT deployed in the framework of smart cities can collect critical water-related data required to enhance water management systems, and contribute to water savings. For example, the San Francisco Public Utilities Commission in the United States of America (USA) has installed one of the largest pilot programmes of smart water meters, with 178,000 water meters equipped with smart sensors to record hourly water consumption. The data are transmitted automatically, four times a day, over a wireless network, and used to detect leakages in the water supply network as well as to analyse patterns in water consumption (San Francisco Water Power Sewer, n.d.). In rural areas, the IoT can improve water use efficiency in irrigation through sensors sending data on weather and soil moisture conditions to the irrigation system in order to optimize watering.

Big Data analytics examines large amounts of data to uncover hidden patterns, correlations and other insights. Applications of big data analytics can help in knowledge gain by processing the collection of continuous streams of water-related information and data, to extract actionable information and insights for improved water management. For example, NASA and the United States Agency for International Development (USAID) have collaborated in the SERVIR-Mekong project to develop a historical flood analysis tool, which analyses satellite imagery from 1984 to 2015 using big data analysis tools and techniques, in order to provide historical patterns of surface water across spatial extents (SERVIR-Mekong, n.d.). The service provides customized information regarding flood-prone areas (e.g. frequency of seasonal flooding cycles) to countries in the Lower Mekong region and supported other disaster preparedness efforts in the greater Mekong region.

Big Data also offers the possibility to integrate additional data to the water-related ones, such as trade patterns or electricity consumption, generating a broader understanding of the evolution of processes that impact on water resources and thus improving the management of water in a changing context, using a cross-sectoral approach.

Various AI-based techniques, models and machine-learning algorithms for effective water quality management are being explored, in particular for the simulation, prediction and forecasting of water quality, for statistical analyses of water quality data, and for the identification of pollution sources (Sarkar and Pandey, 2015; Sengorur et al., 2015; Srivasta et al., 2018). For example, Mohammed et al. (2018) evaluated the use of machine-learning algorithms for the predictive analysis of microbial water quality (the counts of the faecal indicator organisms in raw water) in Lake Maridal in Norway. AI is also emerging as forecasting and optimizing technology for predicting the efficiency of different desalination technologies (Cabrera et al., 2017), developing flood resilience and preparedness (Saravi, et al., 2019), managing aquifers (Moazamnia, et al., 2019), and water use efficiency (Chen, et al., 2017).

Advances in AI and machine-learning techniques may further enhance satellite- and earth observation-based water management and quality monitoring, by enabling and improving the analysis and interpretation of satellite images and geospatial data to support decision-making or to predict water availability and quality parameters (El Din et al., 2017).

13.3 From data to decision-making: bridging the science–policy gap

Knowledge consists of contextualized information, which itself is based on raw data that have been processed, organized, structured and presented so as to make it meaningful and useful. It forms the basis of an informed, science-based decision-making process.

13.3.1 Integrating data into decision-making

ICT tools have helped to generate a large amount of data on climate change, as well as information on mitigation and adaptation responses for water management. However, such data need to be processed, analysed and presented in ways that can be understood and used by decision-makers. The limited use of information and knowledge to inform water resource management policies continues to represent a major challenge for stakeholders in the water sector (whether governments, scientists, the private sector, civil society, etc.). Reasons include a shortage of financial and human resources, a lack of awareness and commitment from the political leadership, gaps in technical skills, and an absence of clearly defined strategies and mechanisms to support overall knowledge management.

One of the main challenges utilities have to contend with is integration. Data acquisition systems may be outdated or insufficiently documented, and they may produce data formats that are idiosyncratic and therefore incompatible with one another. As a result, parallel systems develop, and data gathered by each cannot be cross-processed. A key need for all water-related domains is the fostering of integration and the further development of intersectoral systems, understanding and collaboration. Professionals in each sector need to know more about and understand the thinking and methods applied in the other sectors, in order to continue innovating in a more collaborative, operation-oriented way.

Furthermore, there is also an absolute need to foster the processing of data into information and to encourage the dissemination of knowledge in order to support decision-making (Box 13.1). Promoting openness in content, technology and processes through awareness-raising, policy formulation and capacity-building is a way to broaden access to information, knowledge and technologies. Free and Open Source Software (FOSS) is becoming increasingly popular in low- and middle-income countries where high license costs for paid software may be difficult to overcome. Such tools contribute to greater transparency and accountability in the sector. Visualization tools are also helpful in making climate change-related data intelligible and providing decision-makers with clear, straightforward information.

13.3.2 Citizen science

In the face of climate change, inclusive approaches can empower all water users to take part in the collection, sharing and use of information for mitigation and adaptation purposes. For example, citizen science and crowdsourcing have the potential to contribute to early warning systems and can also provide data for validating flood forecasting models (See, 2019).

For instance, FOSS for knowledge management encourages the participation of civil society in the collection, supply and use of information. Access to information and knowledge has the ability to empower users, including youth, women and the most vulnerable groups, to manage water resources and to contribute to informed decision-making.

Citizen science and crowdsourcing have the potential to contribute to early warning systems and can also provide data for validating flood forecasting models

Engaging citizens in science contributes to speeding scientific discovery, while democratizing reasearch and, potentially, improving or influencing stakeholder decisions (Ryan et al., 2018). Even though citizen science has been widely acknowledged only recently, some historical observations and traditional knowledge records date back centuries. Weather and climate models in the USA have their roots in citizen science efforts that began in the 1800s (Fiebrich, 2009). Such historical observations and records from citizens can be particularly helpful in understanding trends and changes over a longer time. Indeed, individuals can support scientific research by documenting impacts of climate change, in particular by observing and recording changes in ecosystems and natural phenomena, such as the weather, animal and plant behaviours, or certain species prevalence. Citizen science data can also support the calibration of weather instruments and the collection of data on cloud cover, temperature and precipitation to improve the understanding of microclimatic variation (Cifelli et al., 2005; Clark et al., 2015; See et al., 2016; Rajagopalan et al., 2017).

There is a long history of citizens monitoring the water levels in lakes and rivers, and engagement in the water sector has been growing. Citizen science in this area includes, for example, water quality monitoring, with voluntary water quality testing campaigns by local communities and schools (Jollymore et al., 2017; Carlson and Cohen, 2018). There is a large potential to increase the involvement of citizens in hydrology and water resources data collection because of the availability of inexpensive, robust and highly automated sensors, and the possibility to combine them with powerful environmental models to create rich and interactive visualization methods. However, implementation challenges need to be addressed (Buytaert et al., 2014).

Box 13.1 Water Information Network System for bridging the science–policy interface

The UNESCO Intergovernmental Hydrological Programme's Water Information and Network System (IHP-WINS) online platform incorporates data on water resources that are generated with geographical information systems (GIS) into a cooperative and open-access participatory database to foster knowledge-sharing and access to information. IHP-WINS is freely accessible to all, with the aim of encouraging contributors to share information on water. IHP-WINS offers different sets of spatial information that can be overlaid to cross information and highlight new data through maps. Transparency and respect of ownership is guaranteed as all information benefits from metadata in a standardized format and from a Digital Object Identifier (DOI). This allows for an accurate identification and crediting of any contribution, and makes it easier to share information later. The platform is contributing to closing the gap between North and South in terms of access and the sharing of knowledge.

For further information about the IHP-WINS platform, see ihp-wins.unesco.org/.

Scientists are increasingly recognizing the importance of citizen science and crowdsourcing for data collection and recovery in studying climate change and its impacts. For example, projects led by the Pyrenees Climate Change Observatory (OPCC) include components aimed at engaging the public through data collection on flora in the transboundary ecosystems of the Pyrenees and on the nutrient enrichment in peatlands and lakes (OPCC, n.d.). The British Natural Environment Research Council is funding a citizen science project to rescue and digitize two to five million historic meteorological and weather records that were collected by the Meteorological Services of the United Kingdom (UK) between 1860 and 1880 (NERC, 2019). These data could prove helpful in the development and refinement of climate models and scenarios.

Individuals can also contribute to climate action and adaptation through voluntary action and increased awareness. Examples include climate change guidebooks for citizen action (Apel et al., 2010; UNESCO, 2017) and citizen science/action projects. The UNESCO project Sandwatch (UNESCO, 2017) has developed a handbook for climate change adaptation and education in sustainable development in order to engage school students, teachers and local communities in the monitoring of coastal environments in Small Island Developing States (SIDS) (such as beach erosion, pollution, sediment, water quality, etc.) and the development of sustainable approaches to address them. The EarthWatch 'FreshWater Watch' and similar projects foster public engagement through hands-on action in the observation of freshwater quality, pollution and wildlife. Since 2012, the FreshWater Watch community has gathered more than 20,000 water quality samples from around the world, which have been contributed by volunteers, research organizations and schools in Africa, Europe and the UK (EarthWatch Institue, n.d.).

In combining scientific research with public education, citizen science also addresses broader societal impacts in a profound way, by engaging the public in research experiences at various stages in the scientific process and using modern communications tools to involve them (Dickinson et al., 2012). As such, it contributes to closing the science–policy gap.

14

Moving forward

WWAP | Richard Connor, Michela Miletto, Jos Timmerman, Engin Koncagül and Natalia Uribe Pando

This closing chapter constitutes an urgent call for action.

14.1 From adaptation to mitigation

Some of the water-related impacts of climate change on the hydrological cycle can be quite obvious, as exemplified by the increasing frequency and intensity of extreme events such as storms, floods and droughts. But the overall impacts run much deeper. Food security, human health, urban and rural settlements, energy production, industrial development, economic growth, and ecosystems are all water-dependent and thus vulnerable to the impacts of climate change. When climate change impacts upon water resources and water-related services, it deprives people of the exercise of their rights to safe drinking water and sanitation and threatens livelihoods, particularly those of the world's most vulnerable women, men and children.

The interlinkages between water and Sustainable Development Goals (SDGs) have been clearly demonstrated (United Nations, 2018a; 2019; UN-Water, 2019). As such, failure to adapt to climate change not only puts the realization of SDG 6 (the 'water goal') at risk, it also jeopardizes the achievement of most other SDGs. This, in and of itself, would seem sufficient to garner the attention of societies and decision-makers in all sectors and at appropriate levels of government, and to prompt the water and climate change communities to take greater, focused and concerted action in collaboration with other water-dependent sectors, especially in terms of adaptation across the water domain.

Such a call for action is nothing new. In 2003, a global initiative called the *Dialogue on Water and Climate* sought to bridge the knowledge and communication gaps between water managers and climate scientists, and to promote water-related adaption measures through a series of 18 multi-stakeholder dialogues at regional, national and basin levels, collectively highlighting the need to prepare for and adapt to the effects of climate variability and the likely implications of climate change (Kabat and Van Schaik, 2003). Although recognized by some, this call for action, and others like it, have gone widely unheeded. Nearly two decades later, the research has matured and the evidence has accumulated to the point where the process of climate change is accepted as a 'certainty' by all but a very few lone voices among the scientific community. Yet again, however, concrete actions remain largely insufficient.

One thing that *has* begun to change is the recognition and understanding that water, and more specifically improved water management, can be a very important part of the *solution* to climate change.

There has been a long-held belief that mitigation is mainly about energy, whereas adaptation is mainly about water. While somewhat true, this perspective greatly oversimplifies things. Of course, water management needs to adapt to climate change – from countering the effects of floods to addressing increasing water stress for agriculture, industry and other uses. But water management can also play a very important role in climate change mitigation. As described throughout this report, specific water management interventions such as wetland protection, conservation agriculture and other nature-based solutions (NBS) can help to sequester carbon in biomass and soils, while improved wastewater treatment can help reduce greenhouse gas (GHG) emissions and produce biogas as a source of renewable energy.

Converting this knowledge into action is entirely possible, but getting there will require adopting a series of practical and cost-efficient responses, and creating an enabling environment through which positive transformative change can happen.

14.2 Fostering an enabling environment for change

14.2.1 Uniting climate action and water governance

Water is the medium through which societies experience the most severe impacts of climate change. That makes water and climate change everyone's business. Chapter 11 highlights the importance of an equitable, participatory, multi-stakeholder approach to water governance in the context of climate change. Given the cross-cutting nature of water and climate through different economic sectors and across society, trade-offs and conflicting interests need to be addressed at all levels in order to negotiate integrated and coordinated solutions.

Chapter 2 described water as a 'connector' among the global commitments adopted in 2015: Agenda 2030 and the SDGs, the Paris Agreement on Climate Change, and the Sendai Framework on Disaster Risk Reduction. The recognition of water's central role in achieving different international agreements can trickle down into national priorities that in turn support local actions by communities, stakeholders and citizens.

As detailed in Chapter 10, regional and transboundary (basin) cooperation mechanisms offer potential opportunities to further advance climate change adaptation and mitigation components into water development planning and vice versa. Regional and transboundary cooperation can allow for the pooling of resources and can benefit participating entities through improved communication, monitoring and data sharing, sectoral cooperation, capacity support, and (potentially) greater access to funding mechanisms.

14.2.2 Expanding funding opportunities via the climate change agenda

An in-depth examination of the nationally determined contributions (NDCs) submitted by countries as part of the Paris Agreement reveals that, in many cases, water is recognized in terms of policy statements or broad plans (Chapter 10). However, only a very limited number of NDCs actually include the 'intention' of preparing a specific water plan. And while a majority of countries acknowledge water in their NDC's 'portfolio of actions', fewer have estimated the related costs of these actions, and even fewer have included detailed water-related project proposals.

This situation relates directly to finance – an absolutely critical issue as water resources management and water supply and sanitation services have remained notoriously underfunded. Although there is quite a bit of funding available from the climate change funds, most of that funding has been earmarked for mitigation, and has thus not been accessible as a source of financing for water-related projects. Yet, as described in Chapters 3 and 9, a number of water management interventions can and do have aspects of both mitigation and adaptation. Connecting water to climate change would allow countries to leverage additional resources to address the wide overlap between climate and water challenges, and thus improve the outlook of meeting the overall water management goals as outlined in SDG 6.

Food security, human health, urban and rural settlements, energy production, industrial development, economic growth, and ecosystems are all water-dependent and thus vulnerable to the impacts of climate change

As detailed in Chapter 12, there are increasing opportunities to more genuinely and systematically integrate adaptation and mitigation planning into water investments, rendering these investments and associated activities more appealing to climate financiers. Furthermore, various water-related climate change initiatives can also provide co-benefits such as job creation, improved public health (Chapter 5), reducing poverty (Chapter 11), promotion of gender equality, reduced household expenses, and carbon sequestration, among others. Human settlements (Chapter 8), agriculture (Chapter 6), energy and industry (Chapter 7), and disaster risk reduction (Chapter 4) are all critical sectors in which the water–climate connection can be highlighted as part of the NDCs. Underlining such potential synergies as part of the planning process, where applicable, would increase a project's 'bankability' when presented to financiers. All the more so when presented in the context of a 'results-based' framework that incorporates modalities to manage climatic and non-climatic risks and uncertainties.

Moreover, investing in water management pays off in terms of improved availability of water in sufficient quality and quantity, and in avoided costs from extreme events (Chapter 12). Indirectly, a more secure environment in terms of both availability of water and resilience against extreme events provides incentives for increased economic investments.

14.2.3 Enhancing knowledge, capacity and cooperation

Despite the mounting evidence that climate change is affecting the global hydrological cycle, much uncertainty remains when projecting its impacts over smaller geographical and temporal scales (Prologue). However, this uncertainty must not be seen as an excuse for inaction. Rather, it should serve as an impetus to expand research, to promote the development of practical analytical tools and innovative technologies (Chapter 13), and to build the institutional and human capacity required to foster informed, science-based decision-making, and thus be prepared for a changing environment.

As described in Chapter 9, different sectors and stakeholders can face a variety of challenges with respect to both water management and climate change adaptation and mitigation. The often strong interlinkages across the water–climate–energy–food–environment ‘nexus’ can lead to synergies and cross-benefits in some cases, and in others impose difficult choices and trade-offs. Open, interdisciplinary approaches are therefore required to ensure that the various perspectives and knowledge from different disciplines feed into the analyses and inform the decision-making process. The examples of conservation agriculture (Chapter 6) and sustainable land management (Chapter 9) clearly demonstrate how locally applied soil management techniques can have positive effects on water availability and flood control across a catchment (adaptation), while at the same time enhancing soil carbon storage (mitigation).

The need for greater cooperation between the water and climate communities exists well beyond the realm of scientific research. The disconnect remains abundantly clear at the policy level as well – most obviously in the fact that the term ‘water’ is completely absent from the Paris Agreement (UNFCCC, 2015). On the one hand, it is imperative that the climate change community, and climate negotiators in particular, give greater attention to the role of water and recognize its central importance in addressing the climate change crisis. On the other hand, it is equally (if not more) essential that the water community focuses its efforts to promote the importance of water in terms of both adaptation and mitigation, develop concrete water-related project proposals for inclusion in NDCs, and strengthen the means and capacities to plan, implement and monitor water-related activities in NDCs (prior to the 2020 NDC review and beyond).

14.3 Coda

Combining climate change adaptation and mitigation, through water, is a win-win-win proposal. First, of course, it benefits water resources management and improves the provision of water supply and sanitation services. Second, it directly contributes to combating both the causes and impacts of climate change, including disaster risk reduction. Third, it contributes, directly and indirectly, to meeting several of the Sustainable Development Goals (hunger, poverty, health, energy, industry, climate action and so on – not to mention SDG 6, the ‘water goal’ itself) and a host of other global objectives.

In an era characterized by a host of ‘gloom and doom’ studies and articles on climate change and other global environmental crises, and in light of the perceived setbacks of the COP25 meeting, this report proposes a series of practical responses, in terms of policy, financing and action on the ground, to support our collective objectives and individual aspirations to achieve a sustainable and prosperous world for all.

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Abbreviations and acronyms

AFOLU	Agriculture, forestry and other land use
AI	Artificial intelligence
ARC	African Risk Capacity
BAFWAC	Business Alliance for Water and Climate
CCA	Climate change adaptation
CCPA	Climate Change Policy Assessment
CDI	Controlled deficit irrigation
CMIP	Coupled Model Intercomparison Project
COP	Conference of the Parties
CPI	Climate Policy Initiative
CR4D	Climate Research for Development
CREM	Coopération Régionale dans le Secteur de l'Eau au Maghreb – Regional Cooperation in the Water Sector in the Maghreb
CRIDA	Climate Risk Informed Decision Analysis
CRIDF	Climate Resilient Infrastructure Development Facility
CSA	Climate-Smart Agriculture
DALYs	Disability-Adjusted Life Years
DRR	Disaster risk reduction
EbA	Ecosystem-based adaptation
EIP	Eco-Industrial Park
ENSO	El Niño/Southern Oscillation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FOSS	Free and Open Source Software
GCA	Global Commission on Adaptation
GCM	General Circulation Model
GDP	Gross domestic product
GEF	Global Environment Facility
GHG	Greenhouse gas
GIS	Geographical information systems
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH – German Cooperation for International Cooperation GmbH
GRACE	Gravity Recovery and Climate Experiment
GWP	Global Water Partnership
HABs	Harmful algae blooms
HELP	High-level Experts and Leaders Panel on Water and Disasters
HLPF	High-Level Political Forum
HRBA	Human rights-based approach
ICPDR	International Commission for the Protection of the Danube River
ICT	Information and communication technologies
IEA	International Energy Agency
IHP	Intergovernmental Hydrological Programme
ILO	International Labour Organization
IMF	International Monetary Fund
INDCs	Intended nationally determined ontributions
IoT	Internet-of-Things
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature and Natural Resources

IWRM	Integrated water resources management
KJWA	Koronivia Joint Work on Agriculture
LDCs	Least Developed Countries
MAR	Managed aquifer recharge
MCC	Millennium Challenge Corporation
MPGCA	Marrakech Partnership Global Climate Action Agenda
MRSP	Metropolitian Region of São Paulo
NAP	National Adaptation Plan
NAPA	National Adaptation Programme of Action
NASA	US National Aeronautics and Space Administration
NBS	Nature-based solutions
NDCs	Nationally determined contributions
OECD	Organisation for Economic Co operation and Development
OMVS	Organisation pour la Mise en Valeur du Fleuve Sénégal – Senegal River Basin Development Authority
OPCC	Observatorio Pirenaico del Cambio Climático – Pyrenees Climate Change Observatory
OSCE	Organisation for Security and Co-operation in Europe
PET	Potential evapotranspiration
PPIAF	Public-Private Infrastructure Advisory Facility
PV	Photovoltaic
RPJMN	Rencana Pembangunan Jangka Menengah Nasional – National Medium Term Development Plan
RCP	Representative Concentration Pathway
REC	Regional Economic Commission
RICCAR	Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region
SAP	Strategic Action Program
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
SIP	Solar-Based Irrigation Project
SIWI	Stockholm International Water Institute
SLM	Sustainable land management
TDA	Transboundary diagnostic analysis
TIS	Tangshan Iron & Steel
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNECA	United Nations Economic Commission for Africa
UNECE	United Nations Economic Commission for Europe
UNECLAC	United Nations Economic Commission for Latin America and the Caribbean
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCWA	United Nations Economic and Social Commission for Western Asia
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
UNSGAB	Secretary General’s Advisory Board on Water and Sanitation
USA	United States of America
USAID	United States Agency for International Development
WaCCliM	Water and Wastewater Companies for Climate Mitigation
WASH	Water, sanitation and hygiene
WBCSD	World Business Council for Sustainable Development
WFP	World Food Programme
WINS	Water Information and Network System

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Boxes

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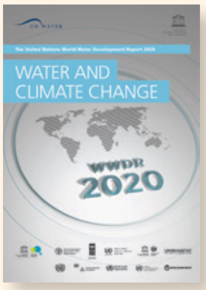

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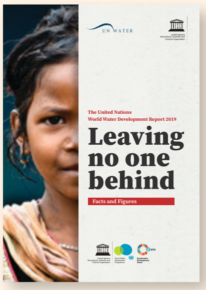

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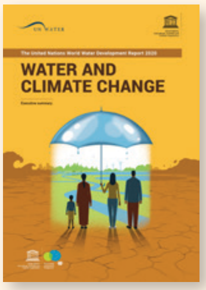

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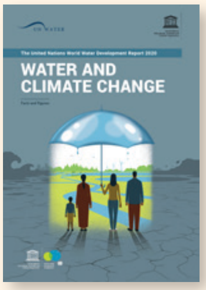

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Sustainable Development Goal 6 Synthesis Report 2018 on Water and Sanitation

The SDG 6 Synthesis Report 2018 on Water and Sanitation was published in June 2018 ahead of the High-level Political Forum on Sustainable Development where Member States reviewed SDG 6 in depth. Representing a joint position from the United Nations family, the report offers guidance to understanding global progress on SDG 6 and its interdependencies with other goals and targets.

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GLAAS is produced by the World Health Organization (WHO) on behalf of UN-Water. It provides a global update on the policy frameworks, institutional arrangements, human resource base, and international and national finance streams in support of sanitation and drinking water. It is a substantive input into the activities of Sanitation and Water for All (SWA).

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The 2020 edition of the WWDR, titled '*Water and Climate Change*' illustrates the critical linkages between water and climate change in the context of the broader sustainable development agenda. Supported by examples from across the world, it describes both the challenges and opportunities created by climate change, and provides potential responses – in terms of adaptation, mitigation and improved resilience – that can be undertaken by enhancing water resources management, attenuating water-related risks, and improving access to water supply and sanitation services for all in a sustainable manner. It addresses the interrelations between water, people, environment and economics in a changing climate, demonstrating how climate change can be a positive catalyst for improved water management, governance and financing to achieve a sustainable and prosperous world for all.

The report provides a fact-based, water-focused contribution to the knowledge base on climate change. It is complementary to existing scientific assessments and designed to support international political frameworks, with the goals of helping the water community tackle the challenges of climate change, and informing the climate change community about the opportunities that improved water management offers in terms of adaptation and mitigation.

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