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Water and Climate Change

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Coursebook

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Water and Climate Change

Coursebook

Contents

Prologue

The state of water resources in the context of climate change

Llamas on the Andean highlands (Bolivia). Photo: © MP cz/Shutterstock.com

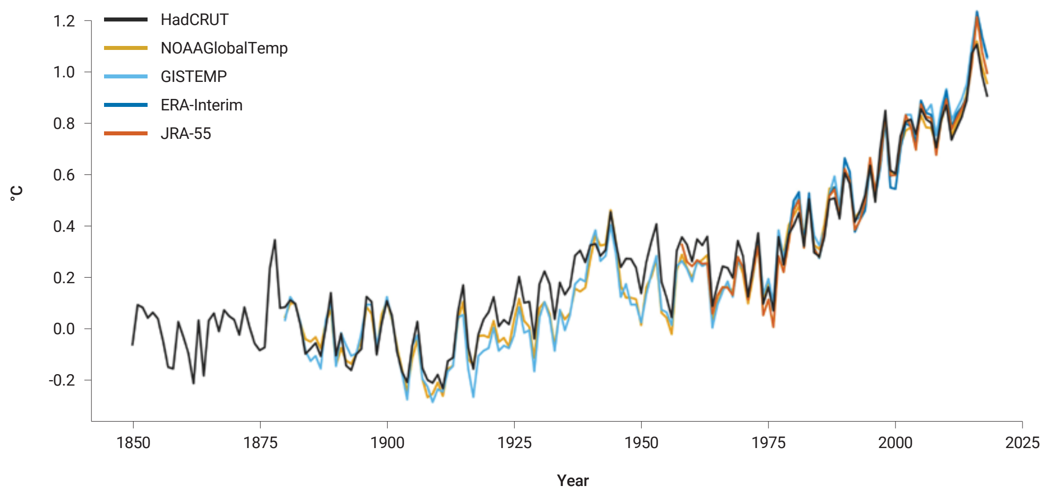
Scientific evidence that the climate system is warming is now unequivocal, with scientific consensus on the role of human activities. Anthropogenic greenhouse gas (GHG) emissions have steeply increased since the pre-industrial era, and atmospheric concentrations of carbon dioxide, methane and nitrous oxide are at levels unprecedented in at least the last 800,000 years (IPCC, 2014a; 2018a; WMO 2019).[1]

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 1). Most of this warming happened in the last 35 years, with five of the warmest years on record having occurred after 2010. Ocean water temperatures also show an increasing trend (Cheng et al., 2019).

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).

Figure 1 Global mean temperature anomalies with respect to the 1850–1900 baseline for the five global temperature datasets



Source: Met Office. © British Crown Copyright.

[1] For all sources cited in this document, please refer to the complete report available at www.unesco.org/water/wwap.

While there is a clear trend in temperature, 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. 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.

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. 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).

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.

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. 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.

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

Water availability and stress

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. 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 (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).

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. Some cities, such as Amman, 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).

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).

Water quality

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).

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.

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 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.

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.

Water-related disasters and extreme events

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).

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).

Water infrastructure

Projections of the needs for water security investment diverge, but they all indicate that the scale of investment ought to increase significantly. Global estimates range from US$6.7 trillion by 2030 to US$22.6 trillion by 2050 (WWC/OECD, 2015). To achieve the water, sanitation and hygiene (WASH) component of the Sustainable Development Goal (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).

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.

Limitations and challenges

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). Photo: © Fernando.RM/Shutterstock.com

1.1 Objectives and scope

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).

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.

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

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. 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.

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).

1.3 The most vulnerable

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.

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.

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.

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).

2

International policy frameworks

Opening of the 71st session of the United Nations General Assembly in New York. Photo: © Drop of Light/Shutterstock.com

2.1 Overview of the main agreements

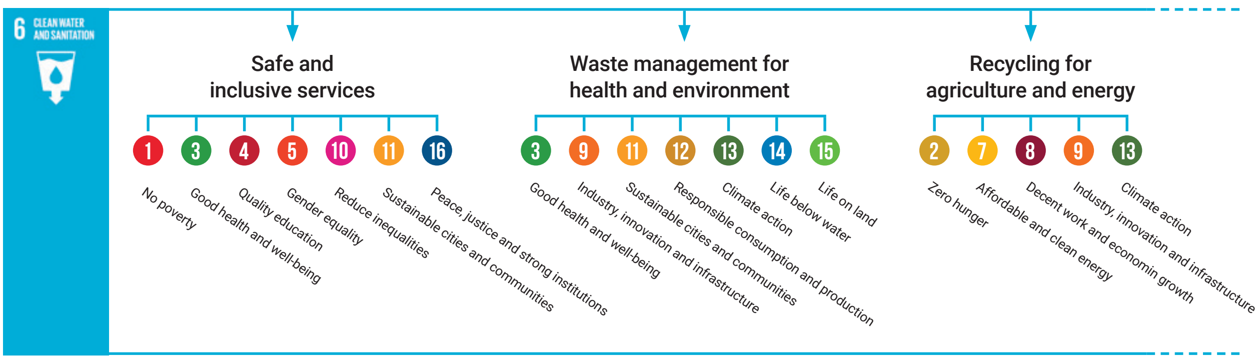
2.1.1 2030 Agenda for Sustainable Development

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).

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).

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 2.1 Connecting the dots



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

2.1.2 Paris Agreement on climate change

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 (EU) submitting intended nationally determined contributions (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. Most identified hazards are also water-related.

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.

2.1.3 Sendai Framework for Disaster Risk Reduction 2015–2030

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).

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).

3

Water availability, infrastructure and ecosystems

Aerial view of a sewage treatment facility. Photo: © Julio Ricco/Shutterstock.com

3.1 Options to enhance water security under a changing climate

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.

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 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 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).

It is increasingly necessary to consider various 'unconventional' and/or regionally underutilized water resources as part of water management and water planning for the future (Qadir and Smakhtin, 2018).

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.

Seawater and brackish water desalination. 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. It is estimated that 0.5 million km³ 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, 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*".

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.

3.2 Mitigation options for water resources management[2]

3.2.1 The water supply and sanitation sector

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.

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.

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.

3.2.2 Water-related ecosystems

Wetlands,[3] 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.

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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2 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).

3 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). Photo: © Ihor Serdyukov/Shutterstock.com

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).[4] 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.

Climate change has made extreme events more severe by altering the timing, intensity and duration of their occurrences (Blöschl et al., 2017). The current impacts and future anticipated risks associated with extreme events demand sustainable solutions for climate change adaptation (CCA) and disaster risk reduction (DRR).

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).

4.3 Opportunities

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.

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.

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

5

Human health impacts related to water, sanitation and climate change

Jakun children learn how to wash their hands properly (Malaysia). Photo: © Farizul Hafiz Stock/Shutterstock.com

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.

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.

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.

5.2 Health risks associated with climate change

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).

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). In addition, climate change-related losses in rainfall and groundwater are likely to increase the demand for wastewater as an irrigation water source. 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).

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. 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.

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. Households are therefore backsliding economically, and even facing economic migration as a consequence of dealing with the additional health burden of climate change. 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).

5.3 Water supply and sanitation response options

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).

Measures such as data collection and monitoring systems, disaster 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.

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).
Photo: © A'Melody Lee/World Bank, www.flickr.com, Creative Commons (CC BY-NC-ND 2.0)

6.1 Introduction

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 GHG emissions and enhance water availability.

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.

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

6.2.1 Agricultural water demand

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).

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 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). 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.

Production of inland capture fisheries is reported at nearly 12 million tonnes (FAO, 2018c). 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).

6.3 The role of agricultural water management in adaptation

6.3.1 Scope for adaptation

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). 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.

6.4 The role of agricultural water management in mitigation

6.4.1 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.

6.4.2 Taking practical agricultural water management solutions for mitigation to scale

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

- 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).
- 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.
- '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).
- Afforestation to sequester carbon may have advantages since regrowth appears to have higher sequestration potential compared with mature forest cover (Pugh et al., 2019).
- 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.

7

Energy and industry

Aerial view of a water treatment plant. Photo: © Avigator Photographer/iStock/Getty Images

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 GHGs are increasing.

Projections by the International Energy Agency (IEA) using their main scenario (New Policies)[5] 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.

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.

7.2 Reactions and opportunities

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).

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. Futhermore, over half the companies reported lower GHG emissions through improved water management.

7.2.1 Greenhouse gas mitigation, energy and water use

There are a number of opportunities to mitigate GHGs and reduce water use at the same time. 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. 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 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.

[5] *"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).

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. 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).

7.2.2 Decarbonizing industry

While creating about 25% of the world's gross domestic product and employment, industry also produced (in 2014) about 28% of global GHG emissions. Ammonia, cement, ethylene and steel manufacturing produced nearly half of industry's CO_2 emissions (McKinsey & Company, 2018).

Opportunities exist to reduce emissions to near zero, one of the most significant being the availability of low-cost zero-carbon electricity[6]. 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.

7.2.3 Adaptation and circular water management

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). 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).

7.3 Moving forward

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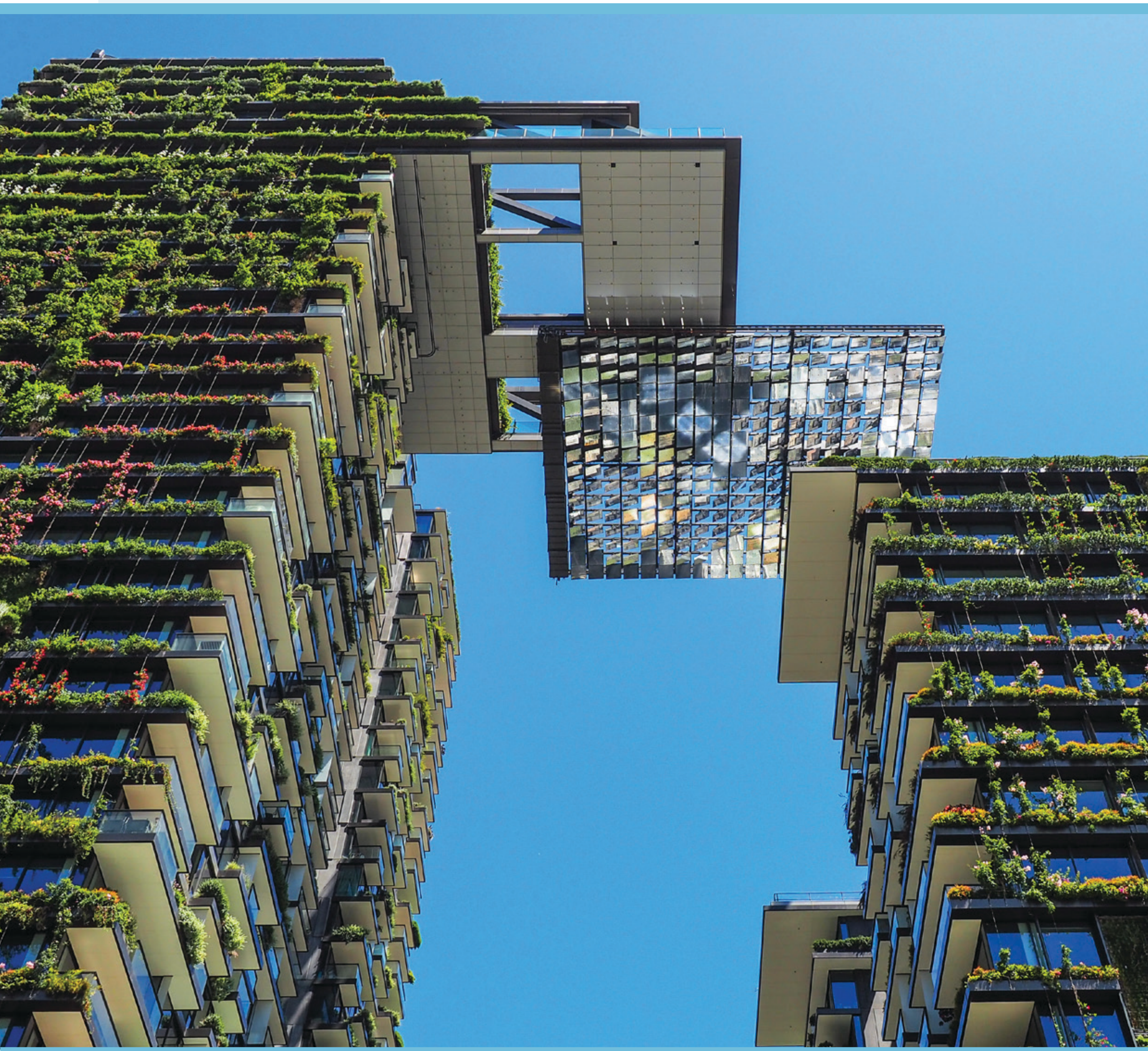
[6] Electricity produced from renewables (carbon-free) and at a competitive cost with respect to fossil (carbon) fuel sources.

8

Human settlements



Green skyscraper building in Sydney (Australia). Photo: © Sakaret/Shutterstock.com

8.1 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.

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. 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.

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.

8.2 Critical areas for action

8.2.1 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, 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.

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.

8.2.2 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.

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.

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.

9

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).
Photo: © Ryan Fletcher/Shutterstock.com

9.1 Western Asia and North Africa

9.1.1 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 Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio- Economic Vulnerability in the Arab Region (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 Least Developed Countries (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).

9.1.2 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 9.1). 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 National Adaptation Programme of Action (NAPA) gives prominence to integrated water resources management (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 9.1).

9.1.3 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,[7] with appropriate capacity support for developing bankable projects.

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[7] A *sukuk* is an interest-free bond that generates returns to investors without infringing the principles of Islamic law (Shariah) (World Bank, 2019).

Table 9.1 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

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.

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

Water governance for resilience to climate change

Global Youth Climate Strike in March 2019 in Sydney (Australia). Photo: © Holli/Shutterstock.com

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).

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, 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).

10.1 Public participation in agenda-setting, decision-making and monitoring

Climate change fundamentally alters the way in which water must be managed. 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). 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, acting as watchdogs towards their decision-makers. 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). 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).

10.1.1 Decision-making under 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. 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.

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).

10.2 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).

Poor people are also more likely to lose relatively more than the non-poor (Hallegatte et al., 2016),[8] 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).

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. Everyday exposure to inadequate water and sanitation kills magnitudes more people – mainly children – than conflicts, earthquakes and epidemics combined.

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.

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[8] 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.

11

Climate finance: Financial and economic considerations

Aerial view of sewage plant treatment in Wrocław (Poland). Photo: © Mariusz Szczygiel/iStock/Getty Images

11.1 Why connect water and climate finance

11.1.1 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 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.

The above expenditures do not include the costlier Targets 6.3 through 6.6 of SDG 6. 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).

11.1.2 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 projects consisted of a fraction of 1% of that sum (CPI, 2018).

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.

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. 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.

11.2 Types of climate investments for water projects

11.2.1 No-regret investments

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. 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.

11.2.2 Results-based climate financing

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 NBSs, 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.

11.3 Using national climate finance for water

As each country's 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.

Several countries and subnational jurisdictions have begun establishing green investment banks, also known as green banks, in recent years. 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).

11.4 Alternative finance sources

11.4.1 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).

One emerging source of private financing that may be useful to water practitioners is the green bond market. The Climate Bonds Standard, a labelling scheme akin to FairTrade certification, has released Water Infrastructure Criteria (Box 11.1) to certify water-related bonds for low-carbon and climate-resilient water management standards (Climate Bonds Initiative, 2018).

Box 11.1 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).

11.4.2 Public-private partnerships

Climate-smart public–private partnerships are another potential way to meet financing needs for climate-resilient water infrastructure investment.

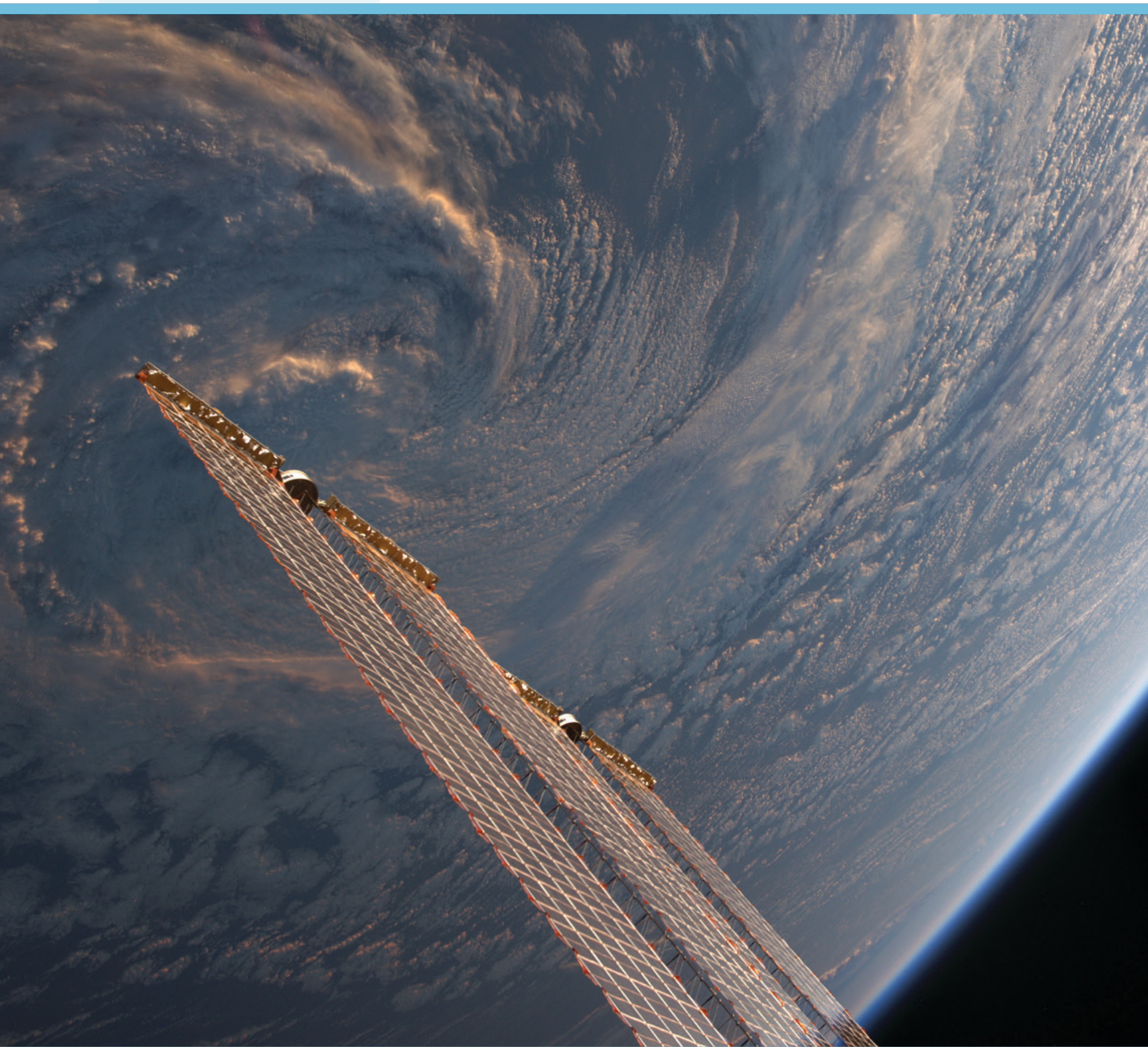
11.4.3 Blended finance

Blended finance "*incorporates different types of financing into a single project or fund*" (World Bank, 2019, p. 24). 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.

For water project developers, especially in Africa, this may be a financing source to watch for future opportunities.

12

Technological innovation and citizen knowledge



A storm at dusk. Photo: NASA, www.flickr.com, Creative Commons (CC BY-NC 2.0)

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.

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.

12.1 Technological innovation

New technologies such as Internet-of-things (IoT), big data, AI and machine learning are also emerging, with diverse applications in reducing uncertainty, mitigating risk and improving resilience to climate change.

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.

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.

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).

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).

12.2 From data to decision-making: bridging the science–policy gap

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.

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.

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.

Scientists are increasingly recognizing the importance of citizen science and crowdsourcing for data collection and recovery in studying climate change and its impacts.

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.

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.

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The United Nations World Water Development Report (WWDR) is UN-Water's flagship report on water and sanitation issues, focusing on a different theme each year. The report is published by UNESCO, on behalf of UN-Water and its production is coordinated by the UNESCO World Water Assessment Programme. The report gives insight on main trends concerning the state, use and management of freshwater and sanitation, based on work done by the Members and Partners of UN-Water. Launched in conjunction with World Water Day, the report provides decision-makers with knowledge and tools to formulate and implement sustainable water policies. It also offers best practices and in-depth analyses to stimulate ideas and actions for better stewardship in the water sector and beyond.

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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