Chapter 9

Freshwater

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Executive summary

Freshwater mobilizes and amplifies the risks to human health and the environment associated with human activities (*established but incomplete*). The global water cycle integrates the impacts of population growth, agriculture, economic development, urbanization, industrialization, deforestation and climate change. All of these impacts affect freshwater quality and quantity. Hence, freshwater is now simultaneously a public good and a risk multiplier, affecting human and ecosystem health through pollutants and through climate change, which is intensifying storms, floods, droughts and desertification of land. Improved governance of every aspect of the water cycle is urgently needed in order to prevent, mitigate and manage these increasing risks. {9.2}

The per capita availability of freshwater in the global water cycle is decreasing with population growth, coupled with the associated agricultural, industrial and energy requirements (*established but incomplete*), while the continents are becoming drier in many places due to climate change impacts. {9.2}

Increasing numbers of people are at risk of 'slow-onset disasters' such as water scarcity, droughts and famine. Such events sometimes lead to increased migration and social conflicts (*well established*) {4.2}. The rising severity and frequency of water-related disasters pose growing risks to social and economic stability, as well as to ecosystems and their life-supporting ecosystem goods and services. There is evidence that water scarcity drives greater competition for available resources, reflected in food insecurity, prices and trade (*established but incomplete*). {9.2}

Groundwater comprises a much larger freshwater volume than surface water. It is increasingly important for water security in many countries and regions (*established but incomplete*). Some major aquifers at subregional and regional levels are threatened by poor management, resulting in unsustainable abstraction levels, groundwater pollution and issues of saline intrusion. {9.4}

Approximately 1.4 million people die annually from diseases associated with pathogen-polluted drinking water and inadequate sanitation, with many millions more becoming ill (*well established*)**.** Some 2.3 billion people still do not have access to safe sanitation. The total global disease burden could be cut by up to an estimated 10 per cent with improved drinking water quality and access, sanitation, hygiene and integrated water resources management. {9.5}

Human illnesses and deaths due to antibiotic- and antimicrobial-resistant infections are increasing rapidly and are projected to become a main cause of death worldwide by 2050 (*well established*). Antibiotics reach the aquatic environment from a wide range of sources, including treated and untreated human waste, agriculture, animal husbandry and aquaculture. Antibiotic-resistant bacteria are now found in both source water and treated drinking water worldwide. {9.5}

New pollutants not easily removed by current wastewater treatment technologies are of emerging concern, including certain veterinary and human pharmaceuticals, pesticides, antimicrobial disinfectants, flame retardants, detergent metabolites and microplastics (*well established*). Endocrine-disrupting chemicals are of particular concern as they are now widely distributed through the freshwater system on all continents. Their long-term impacts on human health include fetal underdevelopment, child neurodevelopment and male infertility. {9.7}

Freshwater ecosystems are disappearing rapidly, representing a high rate of loss of biodiversity and ecosystem services (*well-established*). Wetlands are the natural areas most affected by increasing urbanization, agricultural expansion and deforestation. Approximately 40 per cent of the world's wetlands were lost between 1997 and 2011, and this rate of loss continues. This is linked to an 81 per cent freshwater species population decline over the same period, the highest for any type of habitat (*likely*). The annual economic cost of wetland ecosystem losses between 1996 and 2011 was estimated at US$2.7 trillion. {9.6}

Peatlands (one type of wetland) store more carbon than all the world's forests combined (*established but incomplete*)**.** Climate change is thawing permafrost in boreal peatlands in and around the Arctic Circle, causing increased carbon emissions. Increased drainage and agricultural use of tropical peatlands cause wildfires and release significant quantities of carbon dioxide and methane as greenhouse gases. Altogether, about 15 per cent of peatlands worldwide had been drained by 2015, and currently contribute approximately 5 per cent of annual global carbon emissions. {9.6}

SDG 6 water targets can be realized through engaging the public, private and non-governmental sectors, civil society and local actors in practising effective, efficient and transparent water resources governance (*well established*). {9.9}

Promoting water-use efficiency, water recycling and rainwater harvesting is becoming increasingly important to ensure greater water security and more equitable water allocation for different users and uses (*well established*). {9.9}

The agricultural sector, the largest consumer of freshwater globally, needs substantial improvements in water-use efficiency and productivity (*well established*). The industrial and mining sectors also have strong potential for increasing water-use efficiency, recycling and reuse, as well as limiting water pollution. {9.9}

Limited capacity currently exists to control long-term impacts of aquifer overabstraction and pollution in many locations (*established but incomplete*). Monitoring, modelling and managing aquifer systems are essential to implement sound aquifer and integrated water resources management. Salinization of aquifers resulting from subsidence in river deltas is a complex catchment and coastal urbanization issue (SDG 11), but saline intrusion into coastal aquifers can be controlled by managed aquifer recharge (*well established*). {9.9}

Efficient water use requires water-sensitive urban design of water infrastructure, including conjunctive surface and groundwater development and the promotion of managed aquifer recharge (*well established*). Together with investment in wastewater treatment and recycling, these approaches support water quantity and quality management, and promote drought risk reduction and resilient urban water supplies. At the same time, the provision of drinking water supply and sanitation services to all, as well as leakage control from bulk water supplies, are still challenges in many cities worldwide. {9.9}

9.1 Introduction and priority issues

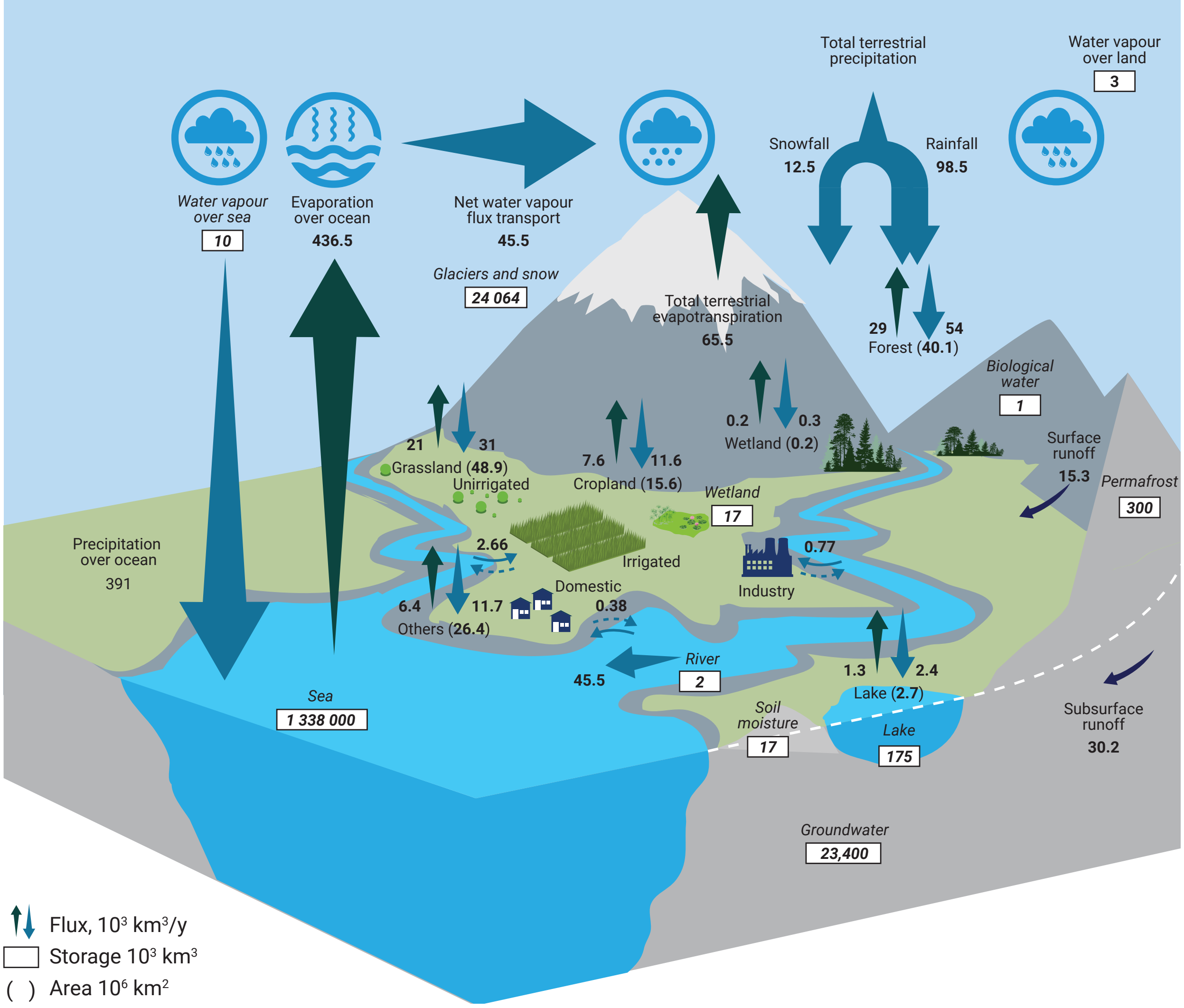
Freshwater is essential for the health and well-being of people, animals, plants, and aquatic and terrestrial ecosystems. The global water cycle is the most important component of weather and climate systems and it is accelerating because of climate change (**Figure 9.1**) (Stocker and Raible 2005; Huntington 2006; Organisation for Economic Co-operation and Development [OECD] 2016, pp. 5-6). The proportion of total freshwater that is readily available as surface water in rivers, lakes and wetlands is 0.4 per cent and decreasing dramatically. Increased floods and droughts (Huntington 2006) and the loss of glaciers (Gao *et al.* 2011; Yao *et al.* 2012; Rodell *et al.* 2018) result in direct and indirect impacts to human and ecosystem health (e.g. Holloway 2003, p. 2; Liu *et al.* 2005; Wang, Wang and Tong 2016; Liu *et al.* 2018).

Water is implicated in most of the Sustainable Development Goals (SDGs), being crucial to food security (SDG 2), health and well-being (SDG 3), energy security (SDG 7), sustainable cities (SDG 11), responsible consumption and production (SDG 12), climate impacts (SDG 13), life below water (SDG 14) and terrestrial biodiversity (SDG 15). Most other SDGs are not achievable without adequate supplies of good quality freshwater (United Nations Water [UN-Water] 2016, p. 9). The sixth Global Environment Outlook (GEO-6) highlights links between water (SDG 6) and health (SDG 3). Degradation of water quality impacts human and ecosystem health (United Nations Environment Programme [UNEP] 2017). Nearly 1.7 million people die annually from preventable diarrhoeal diseases (Lozano *et al.* 2013; Sevilimedu *et al.* 2016, p. 637).

9.2 Pressures on freshwater

Multiple pressures on water resulting from the global drivers of environmental change (see chapter 2) are evident in the rapid deterioration in freshwater quantity and quality in different regions. This is exacerbated in certain regions by pressures from ongoing conflicts, human migration and the cumulative impacts of increasing frequency and severity of droughts,

Figure 9.1: Global hydrological fluxes and storages (expressed in 1,000 km³ per year), illustrating natural and anthropogenic cycles



Source: Oki and Kanae (2006).

floods and storm surges (Intergovernmental Panel on Climate Change [IPCC] 2014). Impacts of natural and human-made disasters are compounded by unsustainable use of freshwater and related ecosystems, which reduces the resilience of the ecosystems (Sheffer *et al.* 2001; Holling and Gunderson 2002). Recent satellite data show that freshwater bodies are rapidly disappearing in many irrigated agriculture areas due to this combination of climate change and overabstraction (Rodell *et al.* 2018).

9.2.1 Climate change

The global water cycle is intimately tied to our changing climate. As the planet warms, the water cycle accelerates, with multiple changes in precipitation patterns putting pressure on freshwater ecosystems (Oki and Kanae 2006). The quantity of salt water is now increasing relative to freshwater due to global warming, land-use changes, melting ice and snow reserves, pumping of groundwater, drying of the continents, and rising sea levels (Bates *et al*. eds. 2008).

Many areas now receive less precipitation than in the past, while others receive more, with most regions experiencing increasingly unpredictable and variable temperature and precipitation patterns. Polar regions and high mountain regions are warming much faster than other parts of the world, with unforeseeable consequences (see Section 4.3.2). A 12 per cent increase in record-breaking high rainfall events occurred globally during 1981-2010 (Lehmann, Coumou and Frieler 2015). By contrast, there is evidence of increasing drought severity in Europe (Vicente-Serrano *et al.* 2014), with historical records indicating increased aridity over many areas since the 1950s (Dai 2011).

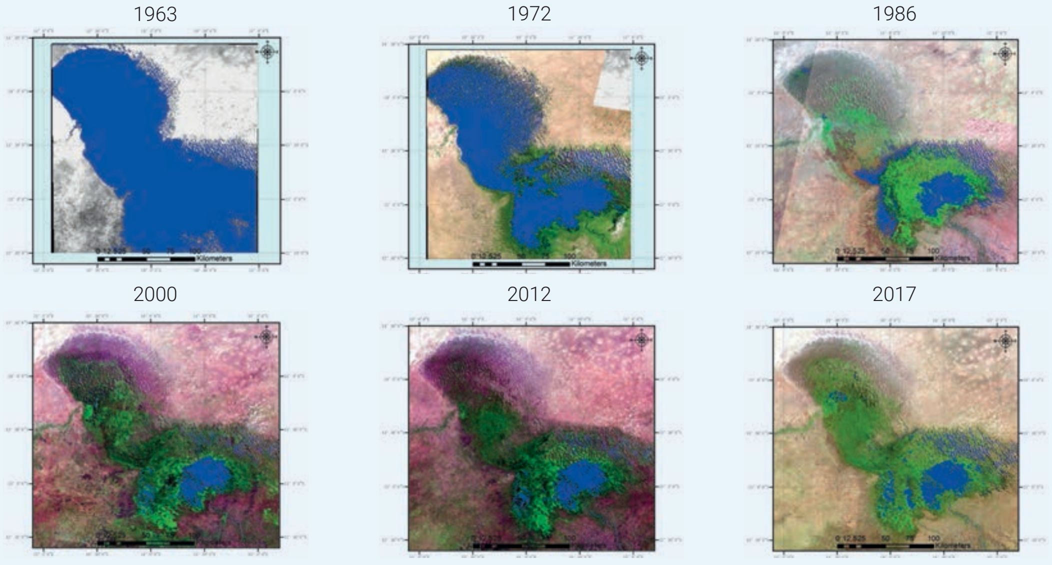
Global climate change interacts with weather and local-scale climate effects, as well as unsustainable water uses and diversions, leading to dramatic impacts such as shrinking freshwater bodies (e.g. Lake Chad, see **Box 9.1**; the Aral Sea; the disappearing wetlands of Islamic Republic of Iran [e.g. Lake Urmia] and the Iraqi Marshes; and even the Caspian Sea (Rodell *et al.* 2018)).

Box 9.1: Impacts of climate change on disappearing lakes and wetlands

Lakes and wetlands are important in regulating water cycles, for example by creating more moderate local climates (Kodama, Eaton and Wendler 1983; Laird *et al.* 2001; Saaroni and Ziv 2003; McInnes 2016; Dai *et al.* 2018). They warm up during the day and lose heat more slowly at night than the land surface, reducing temperature extremes in their basins. Through evaporation, they provide water vapour and precipitation during winter, and they cool and stabilize the local climate in summer. Urban wetlands have been shown to provide a local cooling effect of at least 1-3°C (Filho *et al.* 2017).

Climate change alters water cycles over lakes, wetlands and other standing (lentic) water systems, reducing the quantity of fresh water and waterbody surface area. A warmer climate increases evaporation over the waterbody and adjacent land, but a warmer atmosphere also takes more time to become saturated with water to subsequently produce rainfall. Thus, moisture evaporated from a waterbody may blow away before it can fall as rainfall in its own basin. The basin then becomes drier, with less run-off into the waterbody and associated rivers and wetlands, increasing the need for agricultural irrigation water. These factors collectively accelerate the shrinking of a waterbody, as illustrated in the case of Lake Chad (below), which has lost 90 per cent of its surface area, with an enormous loss of its associated biodiversity, especially fish, and loss of livelihoods for the millions of people dependent upon the lake. Human water use is estimated to account for 50 per cent of the shrinkage and climate change for the remainder (Coe and Foley 2001; Gao *et al.* 2011). The resulting change in microclimate establishes a cycle that further contributes to the drying and desertification of the continent and intensifies the impacts of global climate change.

Figure 9.2: Shrinkage of Lake Chad



1963 1972 1986

2000 2012 2017

Sources: Hansen *et al.* (2013); Guzinski *et al*. (2014).

Too much rainfall brings pollution, soil erosion, avalanches and mud slides which, together with floods, tornadoes and cyclones, are responsible for much physical damage to infrastructure, loss of life and injury. Too little rainfall causes drought, extreme wildfires, sandstorms, soil degradation and increased competition over water sources, often leading to the accelerated shrinkage and loss of these goods. Collectively, these realities and risks have grave socio-political, economic, environmental and ecological implications, making better management and governance of freshwater resources an imperative.

9.3 Water and land use

Growing cities and agricultural intensification are increasingly depleting both surface water and aquifers. Wetlands are being drained, and many rivers, lakes and ponds are vanishing in water-scarce regions. Land-use changes result in surface hardening of natural areas, reducing infiltration and aquifer recharge, while increasing water run-off and pollution. Land degradation and deforestation also cause increased run-off, carrying eroded sediment through rivers into oceans (see Section 8.4.2). In areas experiencing large-scale deforestation, the likelihood of precipitation events is decreasing and soil erosion is increasing (Birkinshaw *et al*. 2011; Ellison, Futter and Bishop 2012).

Agriculture is responsible for an average 70 per cent of global water withdrawals (UN-Water 2017). Industrial processes and energy generation increasingly compete with agriculture and cities for available water. However, much energy water demand is for non-consumptive uses (e.g. cooling) (UNEP 2012a).

The interconnections between water, energy security and food security have identified tensions and trade-offs between them requiring careful scrutiny and consideration (Rosengrant *et al.* 2009). This nexus becomes especially important when considering drivers such as urbanization, population, economic growth, technology and innovation (Bleischwitz *et al*. 2018).

9.4 Global state and trends of freshwater

9.4.1 Water quantity

Geographic variations, coupled with climate change, result in uneven distribution of rainfall and freshwater sources, with deserts and rainforests highlighting these water availability extremes (**Figure 9.1** and **Figure 9.4**). Groundwater is the major drinking water source for the majority of people globally, particularly in arid regions and during drought. The estimated available renewable groundwater resource in Africa is more than 100 times that of total annual renewable surface-water resources (MacDonald *et al*. 2012, p. 5). However, deeper aquifer water is constrained by exploration and abstraction costs. Abstraction of very ancient 'fossil groundwater' is unsustainable, because this is not a renewable resource.

9.4.2 Water withdrawals

Human and environmental water demands vary spatially and culturally across rural and urban areas. While an average of 70 per cent of water withdrawals worldwide are for the agricultural sector, this varies widely across regions and countries (Hoekstra and Mekonnen 2012, p. 3232; Food and Agriculture Organization of the United Nations [FAO] 2016; UN-Water 2017). South-East Asia uses more than 80 per cent of its available freshwater for agriculture (FAO 2016).

The North American region has the highest per capita freshwater use (Hoekstra and Mekonnen 2012, p. 3232; UNEP 2016a, p. 71), although increased water-use efficiency is helping to lower demand, despite population and economic growth (UNEP 2016a, p. 71). Water withdrawals by all sectors in the United States of America (**Figure 9.3**) illustrate high water usage for cooling in electricity production.

Groundwater is increasingly important globally, representing estimated withdrawals of about 982 km^3 (Margat and van der Gun 2013), equivalent to nearly 33 per cent of total water withdrawals (Seibert *et al.* 2010, p. 1863; Famiglietti 2014, p. 945). Since conventional groundwater withdrawal technology is easily accessible to landowners, extraction is highly decentralized. Groundwater in confined artesian basins (Bundesanstalt für Geowissenschaften und Rohstoffe [BGR] 2008) can be accessed at depths of up to 2 km, and often provides a strategic water resource, especially during droughts (e.g. Great Artesian Basin, Australia [GABCC] 2016); Table Mountain Group, South Africa) (Hay and Hartnady *et al*. 2001; Weaver *et al*. 2002; Blake *et al*. 2010).

Industries that abstract from aquifers include industrial agriculture, mining, geothermal energy and ground-source heat pumps, disposal and/or storage of hazardous wastes (e.g. landfills, nuclear waste), fluid injection (e.g. oil and gas extraction through hydraulic fracturing or 'fracking' and associated wastewater reinjection), and underground construction activities. Such pressures are leading inexorably to stronger competition/interactions between the different industries, with sometimes unforeseen consequences.


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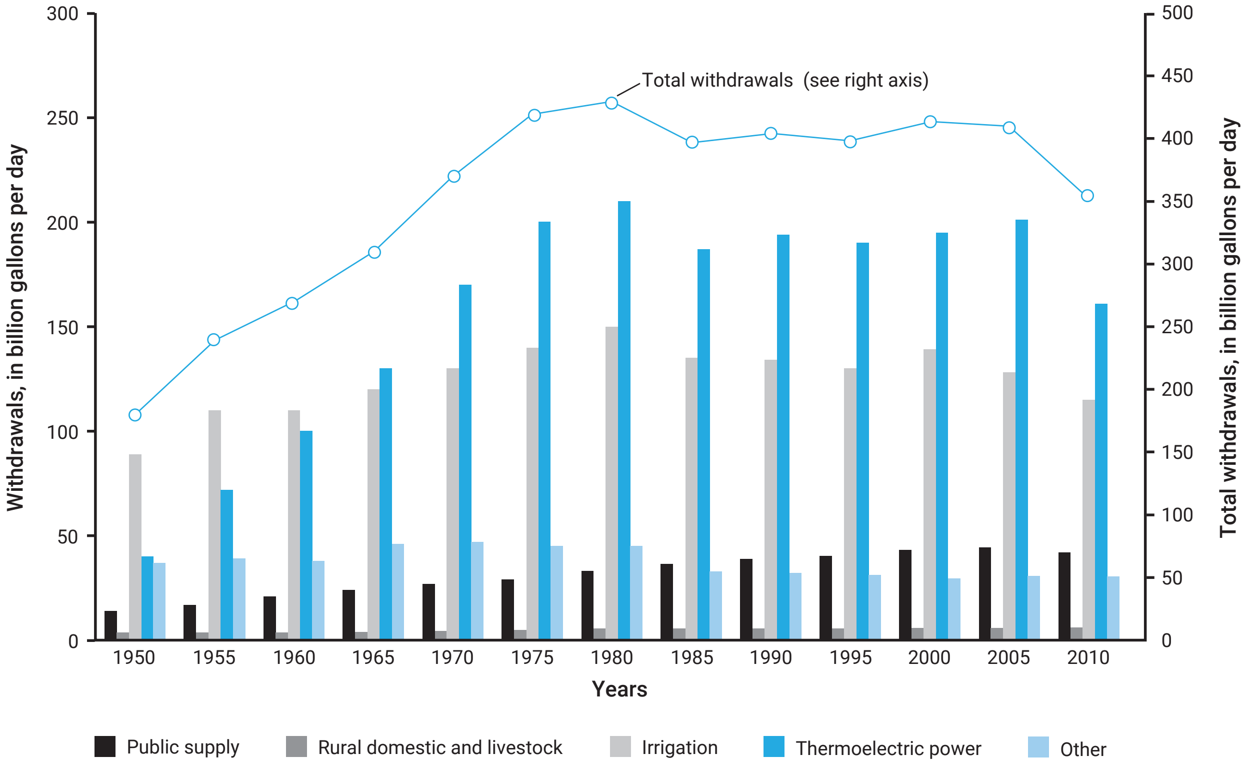
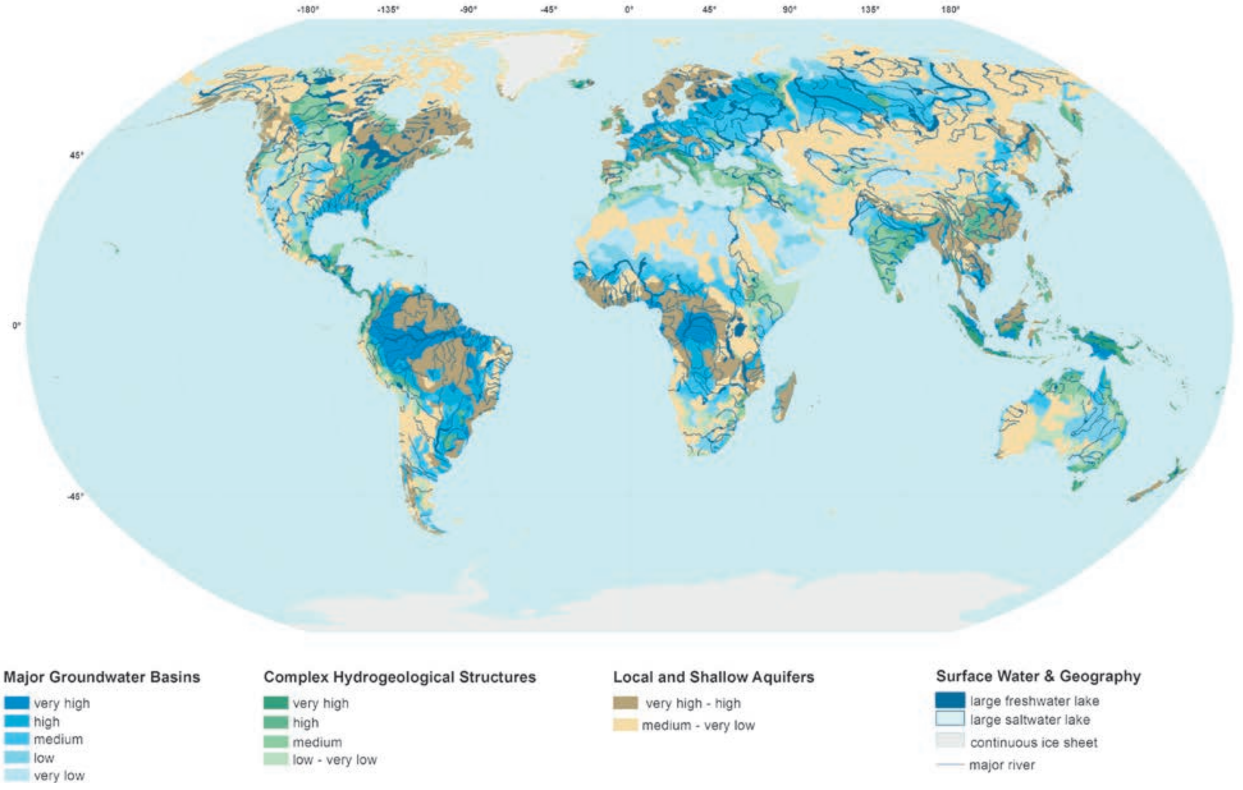
Figure 9.3: United States water withdrawals from all sources (1950-2010)



Note: 1 billion gallons = 3.8 million m^3.

Source: Maupin *et al*. (2014, p. 46).

Figure 9.4: Global hydrogeological map illustrating various aquifers and groundwater resources



Source: BGR and United Nations Educational, Scientific and Cultural Organization [UNESCO] (2008).

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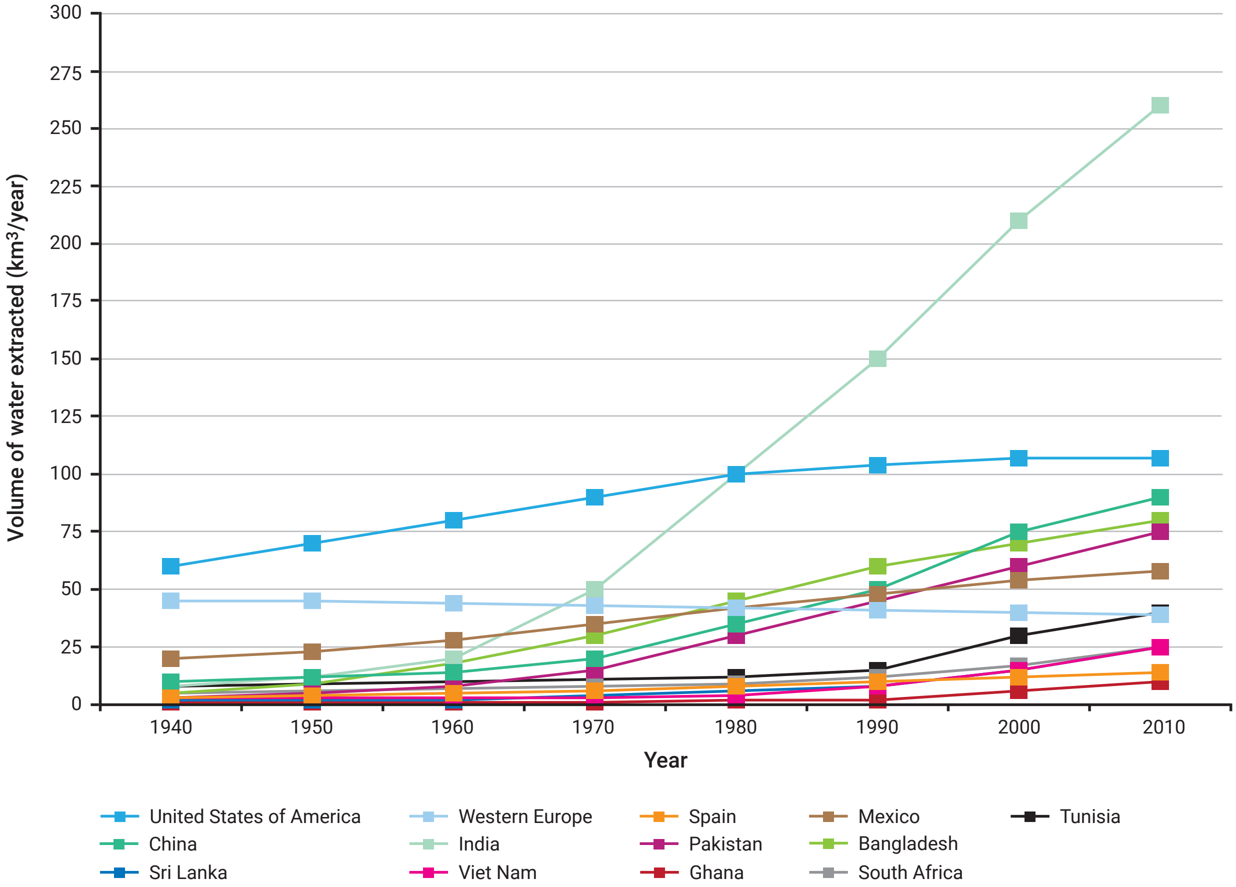
Figure 9.5: Global trends in increasing groundwater use



Source: Shah (2014, p. 12).

Groundwater use has plateaued in some regions but is increasing elsewhere (**Figure 9.5**), such as in Asia and the Pacific and West Asia (e.g. about two-thirds of freshwater utilized in West Asia). About 75 per cent of European Union (EU) inhabitants rely on groundwater for drinking (European Commission 2008, p. 7), and groundwater use, compared with surface water, has increased substantially to 1.3 trillion m^3 per year across North America (Famiglietti and Rodell 2013, p. 1301). Groundwater accounts for 30 per cent of water withdrawals in Latin America (Campuzano *et al.* 2014, p. 38) and an estimated 75 per cent of the African population depends on it (Altchenko and Villholth 2013, p. 1498). It must be noted, however, that estimates of groundwater withdrawals and use vary widely, constituting a critical data gap.

Increased agricultural groundwater use has led to rising depletion rates in major aquifers in arid and semi-arid zones (UNEP 2012b). Pumping rates that for decades have exceeded long-term natural recharge have resulted in some larger aquifers being 'mined' unsustainably (Famiglietti 2014, p. 946). Five of the world's seven largest aquifers are in Asia and the Pacific, and are overstressed (UNEP 2016b, p. 84).

Excessive groundwater abstraction has caused land subsidence in some coastal cities (e.g. Bangkok; Ho Chi Minh City; Jakarta; Manila) (UNEP 2016b, p. 87). Overexploitation of an aquifer can also impact wetland ecosystems. Hydraulic fracturing (fracking) for oil and gas extraction merits concern for its groundwater impacts (see **Box 9.2**). Groundwater is often underexplored on some islands due to surface-water availability, while other islands can be wholly reliant on it. Climate change impacts may lead to a greater reliance on and pose a threat to ground water because of sea level rise. Further studies are needed since islands are experiencing increasing freshwater shortages (Famiglietti 2014, p. 946).

9.4.3 Glacial retreat

Climate change is affecting regional water availability around the world, especially in areas reliant on glacial meltwater. Rivers originating in the Hindu-Kush Himalayas are among the most meltwater-dependent systems, and the source of ten large Asian river systems (Amu Darya, Brahmaputra, Ganges, Indus, Irrawaddy, Mekong, Salween, Tarim, Yangtse, Yellow), providing water for 20 per cent of the world's population (UNEP 2016b, p. 81) (**Figure 9.7**).

Box 9.2: Water quality impacts of mining

Modern mining generates large volumes of tailings (finely ground rock remaining after extracting ore) and waste rock (non-mineralized rock; low-grade ore), often containing iron sulphide minerals (e.g. pyrite). Exposed to the surface environment, these can react with water and oxygen to form sulphuric acid, producing acid metalliferous drainage (AMD). AMD can degrade water quality and impact aquatic biodiversity. Recent tailings dam failures (e.g. Mount Polley, Canada; Samarco, Brazil) demonstrate that mine wastes escaping into the environment can also significantly impact aquatic ecosystems and biodiversity, with tailings particles smothering riverbeds, reducing light penetration and oxygen levels, and affecting river geomorphology (Mudd *et al.* 2013).

Figure 9.6: Examples of surface streams affected by acid and metalliferous drainage (AMD) and/or tailings discharges: (left) Urban stream severely affected by AMD in western Witwatersrand Basin, Johannesburg, South Africa; (right) Tailings sediment from Samarco Dam

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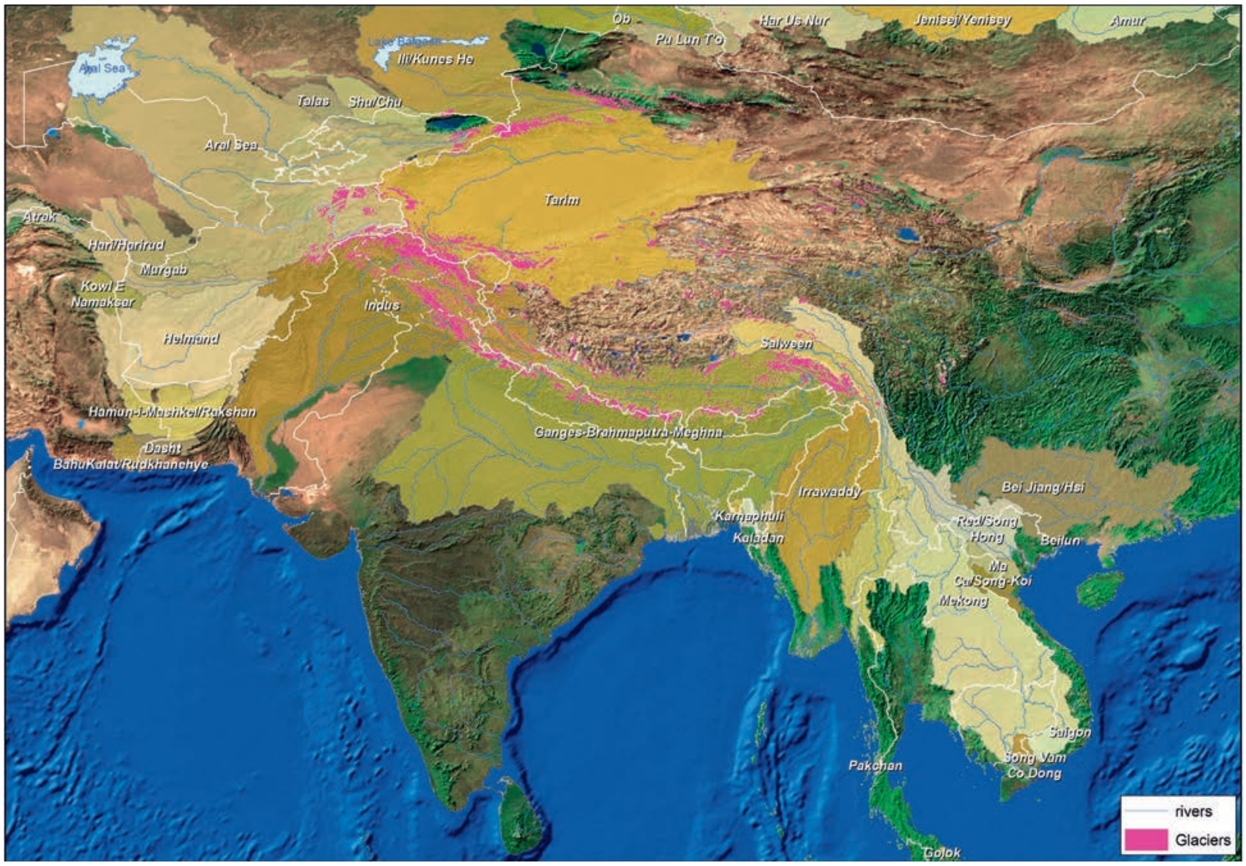
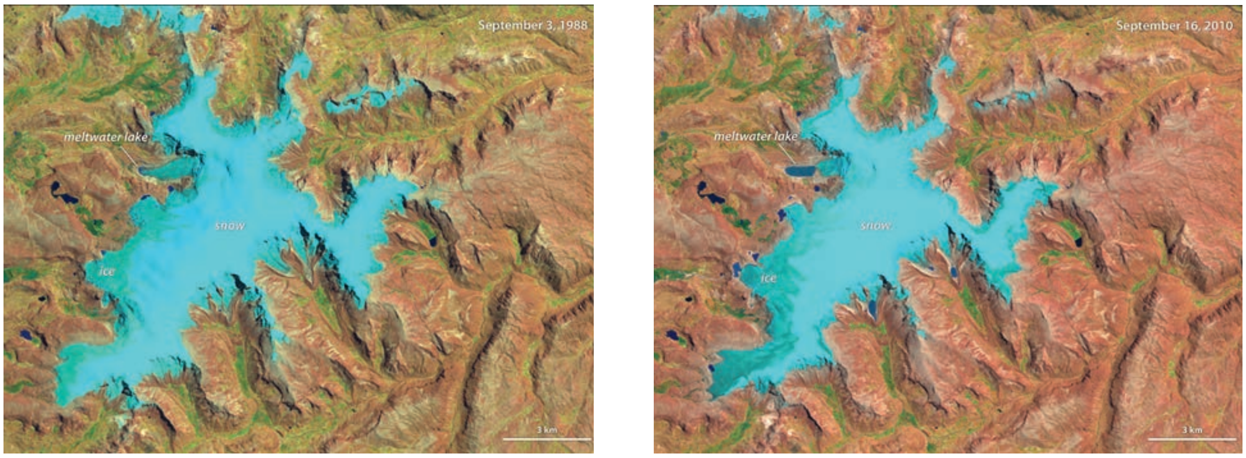
Figure 9.7: Rivers originating in the Hindu-Kush Himalayas are among the most meltwater-dependent systems



Sources: UNEP and Global Environment Facility [GEF] 2018; Global Land Ice Measurements from Space [GLIMS] 2018.

Figure 9.8: Retreat of Quelccaya ice cap in Peru between 1988 (left) to 2010 (right)



Source: Schoolmeester *et al.* (2018).

Tropical glaciers in the Andes account for more than 80 per cent of available freshwater for downstream populations and ecosystems in Latin American semi-arid tropic regions (UNEP 2013, p. 1). These are melting at an accelerating rate attributed to climate change (Chevallier *et al.* 2011; Rabatel *et al.* 2013), raising concerns about sustainable water supplies (**Figure 9.8**). Glacial retreat in the European Alps has accelerated over the last two decades (Huss 2012, p. 1132), while Central Asian glaciers have lost 27 per cent of their mass and 18 per cent of their area (Farinotti *et al.* 2015, p. 720; Yao *et al.* 2012).

9.4.4 Water scarcity

Water scarcity is defined as less than 1,000 m^3 per capita of available, renewable freshwater per year (United Nations World Water Assessment Programme [WWAP] 2012, p. 124). The differentiation between areas of economic water scarcity (where storage, treatment and conveyance infrastructure are lacking) and absolute or physical water scarcity is illustrated in **Figure 9.9** (WWAP 2012).

Sustainable freshwater supplies from surface and groundwater sources are critical for human and ecosystem needs, and for achieving the SDGs. Excessive withdrawals are often the cause of water scarcity. Lack of infrastructure, combined with rapid population growth, can lead to economic water scarcity, although there is not always agreement about the cause of water scarcity being physical, economic or indeed political in nature. Water of appropriate volume and quality is not always available at the right time or in the right place for a specific use.

Water scarcity is common throughout West Asia and the Asia and the Pacific region, and in arid parts of Africa, Latin America, the western United States of America and the Middle East. Factors that typically stress water resources include large populations, agricultural expansion and intensification, rainfall variability, rapid development, increasing urbanization, industrialization and climate change. The desiccation of the Aral Sea in Central Asia remains one of the most dramatic water-related environmental disasters of the 20th century. Most global climate model projections predict a 20 per cent rainfall decrease over the next 50 years in West Asia, with increased temperatures, evaporation and relative humidity all influencing water availability (UNEP 2016c, p. 12).

Desertification is a pressing problem in Africa's sub-Saharan region, arising from climate change and internal migration (UNEP 2016d). Although physical and economic water scarcity prevails across Africa, its surface- and groundwater resources are considered underdeveloped, in terms of meeting human livelihood and development needs (UNEP 2016d). In this context, many small- to medium-scale water infrastructure projects are well suited to local water demand.

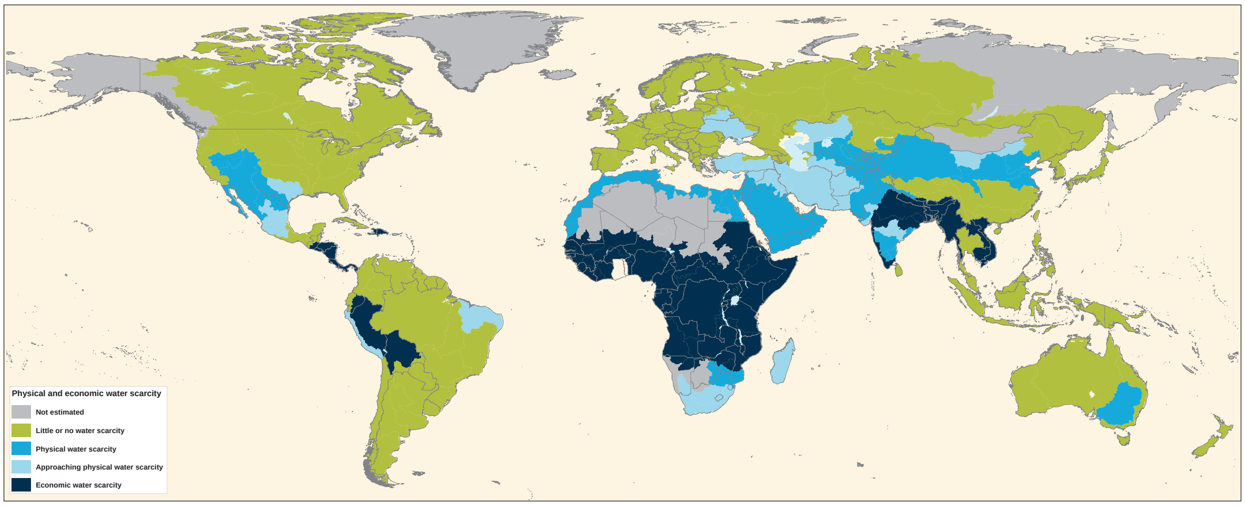
In parts of the developed world (e.g. Europe, North America, Australia), water scarcity is a challenge that is commonly addressed through large water infrastructure projects, such as dams, long-distance pipelines and desalinization plants. Given expected population growth trends, regions such as the Middle East, Africa and Asia need to address water scarcity in innovative and scale-appropriate ways, including water governance, rainwater harvesting and wastewater recycling, leapfrogging the conventional solutions of the past.

9.5 Water quality

Although natural processes also generate water pollutants, human activities related to population growth, urbanization, agricultural expansion, transportation, and human and industrial waste discharges are typically the main sources of water pollution (UNEP 2016e). They include pathogens, nutrients, heavy metals and organic chemicals (Annex 9-1) from point sources (domestic, industrial or sewage pipeline discharges; septic tank leakage) and/or catchment non-point sources (land surface run-off from extensive diffuse agricultural use and urban areas following rainfall and snowmelt events).

Water quality in many Latin American, African, Asian and Pacific rivers has generally decreased since the 1990s, although the majority are still in relatively good condition (UNEP 2016e). Water quality in many European rivers has improved since adoption of the EU Water Framework Directive

Figure 9.9: Global physical and economic water scarcity



Source: WWAP (2012, p. 125).

in 2000. About half of United States waters do not meet standards protective of aquatic life, with more than 40 per cent not meeting recreational-use standards (UNEP 2016a). The water quality of many lakes and reservoirs is particularly endangered worldwide because of their long water residence times and tendency to accumulate pollutants (International Lake Environment Committee Foundation [ILEC] and UNEP 2016).

Groundwater pollution sources include non-point agricultural and urban run-off, on-site wastewater treatment, oil and gas extraction and fracking activities, mining, and industrial sources (Foster *et al.* 2016). Natural contamination occurs in some cases (e.g. sodium-chloride salinity, arsenic, fluoride, radioactivity in fossil groundwater aquifers). Human health impacts from untreated groundwater are of particular concern (Morris *et al.* 2003; UNEP 2016e).

9.5.1 Pathogens

Water-borne diseases remain major challenges in many African, Asian, Pacific and Latin American cities and rural communities (Annex 9-1). Although collection and treatment of human excrement has largely curtailed the problem in developed countries, sewage outfalls still generate large pathogen loads. However, parasites can survive waterbody conditions for many weeks, while viruses may survive drinking water treatment.

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Pathogens remain a major cause of human death and illness, particularly in developing countries (http://www.who.int/water_sanitation_health/takingcharge.html). High child mortality, for example, is associated with diarrheal diseases from contaminated water in Africa, Asia, the Pacific and Latin America (Annex 9-1). Principal pathogen sources include inadequately treated human and livestock wastes, and combined sewer overflows and leaks. **(Figure 9.10)**

Irrigation with inadequately treated or diluted wastewater occurs in many developing countries, increasing agricultural productivity for many poor communities, but often at the expense of human health and environmental risks. Comparison studies highlight environmental degradation and higher water-borne disease rates in wastewater-irrigated areas (75 per cent prevalence rate for gastroenteritis in children 8-12 years of age, compared with 13 per cent in freshwater-irrigated areas) (Grangier, Qadir and Singh 2012).

Antibiotic and antimicrobial resistance is a major global health concern, with the spread of resistant bacteria and resistance genes in the environment being a critical component of integrated control efforts (Berendonk *et al.* 2015). The major source remains human and animal excreta, with aquaculture increasingly adding to the levels in the water environment (Kümmerer 2009). The World Health Organization (WHO) predicts antimicrobial resistance to become a major cause of deaths globally by 2050 (Annex 9-1). Wastewater-treatment plants have diverse abilities to remove antibiotic-resistant bacteria, and limited capacity to remove antibiotic drugs (Pruden *et al.* 2013; Berendonk *et al.* 2015).

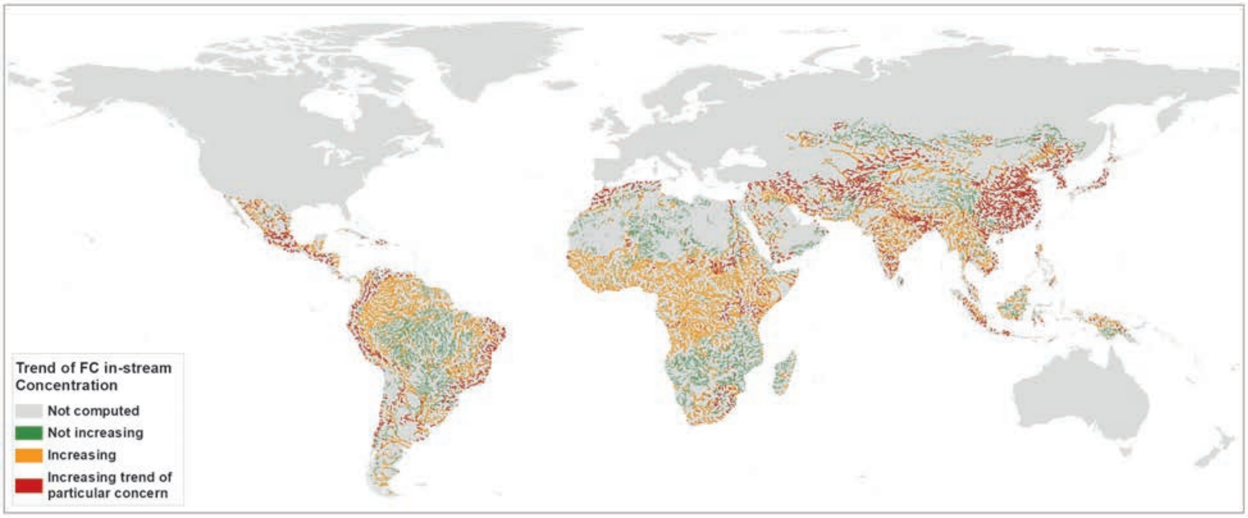
9.5.2 Nutrients

Eutrophication represents the natural ageing process of lakes and wetlands, wherein they become enriched with nutrients and sediments, becoming more biologically productive, usually over a long period (Annex 9-1). Human activities can greatly increase these nutrient loads, accelerating this process, with detrimental effects on the whole ecosystem. The resulting algal blooms and aquatic plant growths interfere with many human water uses and can greatly affect the balance and diversity of aquatic flora, fauna and algal species (OECD 1982; Research Center for Sustainability and Environment-Shiga University and ILEC 2014). Major nutrient sources include inadequately treated domestic sewage discharges, urban and agricultural run-off, aquaculture and mariculture. Algal blooms can turn lakes, reservoirs and slow-moving rivers turbid and green in colour, depleting the water's oxygen content when algae die and undergo decomposition. Some blue-green algal species are toxic to fish and livestock (O'Neil *et al.* 2012) and affect human health. A clear relationship between climate change and eutrophication of lakes has also been reported (Jeppersen *et al.* 2010).

More than half of the total phosphorus loads in the five UN Environment regions originate from inorganic agricultural fertilizer run-off **(Figure 9.11)**. Livestock waste used as fertilizer can also be problematic because its nitrogen-phosphorus ratio is higher than that needed by crops, thereby potentially saturating soils with phosphorus, which can then reach waterbodies via non-point source run-off. River nutrient contributions to coastal areas almost doubled during 1970-2000 (Annex 9-1). The Gulf of Mexico exhibits a 'dead zone' typically covering nearly 13,800 km^2 attributed to nitrogen from grain fields in the midwestern United States of America carried down the Mississippi River, with eventual decay of the algal growth consuming the oxygen in the water, suffocating marine life. There are nearly four times as many dead zones (400) in the oceans now as there were in 1950, including in the Mediterranean Sea (Pearce 2018).

Some major urban areas in Asia and the Pacific experience groundwater nitrate concerns from sewer and septic tank leaks (Umezawa *et al.* 2009), and rural areas in many countries are affected by excessive chemical fertilizer application (Novotny *et al.* 2010). The effects of nitrates in groundwater has long been a public health concern, particularly as a causative factor in methemoglobinemia in infants ('blue baby' syndrome).

Figure 9.10: Model estimates of trends in faecal coliform bacteria levels in rivers during 1990-1992 and 2008-2010



Orange or red river stretches indicate increasing concentrations between these periods; red river stretches indicate increasing trends of particular concern.

Source: UNEP (2016e).

Although over half of EU surface waters improved during 1992-2010 (average river phosphate and nitrate levels decreasing by 57 per cent and 20 per cent, respectively), many still do not meet European Water Framework Directive environmental objectives (European Union 2000).

9.5.3 Sediments

Sediments result from erosion of exposed soil surfaces, with much eroded soil being deposited in basins throughout the world, including in Africa, Asia and Latin America. Deforestation, poor agricultural and livestock practices, intensive fuelwood harvesting, mining, urbanization and unplanned settlements are major causes of soil vulnerability to erosion, and storm-generated run-off carries soil into downstream waterbodies (Annex 9-1). Sediment-associated pollutants can have human health impacts, and interfere with water uses and aquatic organism metabolism and habitats (UNEP 2017). Artificial channels from dams and urban development can change sediment flow paths, lead to erosion and reduce sediment available to build up banks, river deltas and beaches along coastlines, causing aquatic ecosystem changes (Blum and Roberts 2009, Syvitski *et al.* 2009; Yang *et al.* 2011; Cloern and Jassby 2012; Adams *et al*. 2016; Yihdego, Khalil and Salem 2017).

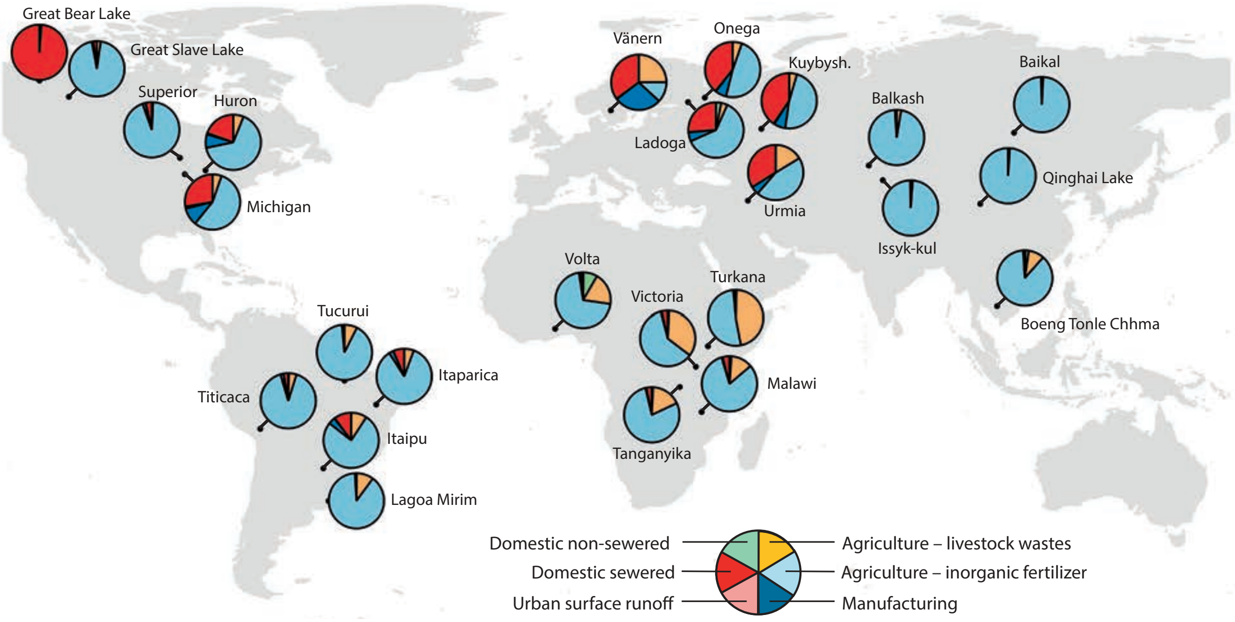
9.5.4 Organic pollutants

Biodegradation of organic pollutants such as liquid manure, sewage effluents and sewage treatment sludge can deplete oxygen concentrations in waterbodies, causing fish kills and releasing heavy metals from bottom sediments back into the water column, a process characterized by a high biochemical oxygen demand (BOD) from microbial decomposition of these pollutants. Algal bloom decomposition also can deplete the oxygen content in eutrophic waterbodies, particularly lakes and wetlands.

Based on model analyses, BOD concentrations increased in many parts of Africa, Asia and the Pacific, and Latin America during 1990-2010 from industrial and domestic wastewater discharges, and agricultural and urban run-off, with highest increases in rapidly urbanizing and industrializing countries (Annex 9-1). BOD pollution in most developed countries has significantly decreased with enhanced wastewater treatment (e.g. implementation of the 1991 EU Urban Wastewater Treatment Directive).

Synthetic organic pollutants include pesticides, industrial chemicals and solvents, and personal care and pharmaceutical products. Persistent organic pollutants (POPs) are particularly problematic because they do not readily biodegrade in the aquatic environment. Used in many industrial and agricultural applications, they can impact human health and aquatic ecosystems, persisting in fatty tissues of humans, fish and other organisms, and accumulating in sediments. DDT has human carcinogenic and teratogenic risks, for example, but is still used in many regions to control malaria (Annex 9-1). Other synthetic compounds, including non-POPs, continue to enter the ecological food chain globally, while others, such as endocrine-disrupting chemicals, are considered contaminants of emerging concern (see Section 9.5.7). Neonicotinoid and fipronil systemic insecticides, for example, are water soluble and can leach into freshwater and marine systems. Neonicotinoid insecticides are toxic to most arthropods and invertebrates, while fipronil is toxic to fish and some bird species (Annex 9-1; van Lexmond *et al.* 2015; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 2017).

Figure 9.11: Sources of anthropogenic total phosphorus loadings to lakes (five largest lakes by surface area in each of the five UN Environment regions), showing average percentage contributions in 2008-2010 annual loads



Source: UNEP (2016e).

9.5.5 Heavy metals

Used in a range of industrial and agricultural sectors, heavy metals exhibit widespread environmental distribution. Heavy metals from industrial activities, and large-scale and artisanal mining, have seriously degraded water in some Asian, Pacific and South American countries (Da Rosa *et al.* 1997; Spitz and Trudinger 2008; Sikder *et al.* 2013; Annex 9-1). They can bioaccumulate in plants grown with contaminated irrigation water (Arunakumara, Walpola and Yoon 2013; Lu *et al.* 2015). Many (mercury, lead, chromium, cadmium) are toxic to humans and aquatic organisms (Kim *et al.* 2017).

Heavy metals associated with water-intensive mining are problematic in Africa and Latin America (Annex 9-1). Water drainage from active and abandoned mines can cause significant water degradation (e.g. mercury and arsenic used in gold mining can pollute surface and groundwater). Examples of untreated mine-water discharging into streams and rivers include Mount Morgan (Australia) and Tisza River (Hungary), where reservoirs, agricultural irrigation water and aquatic ecosystem biodiversity have all been degraded. Groundwater pollution also has been reported to have occurred in Alberta, Canada because of the tar sands industry (Timoney and Lee 2009).

Groundwater contamination with naturally occurring arsenic occurs in South Asia and other countries in Asia and the Pacific (Rahman, Ng and Naidu 2009; Annex 9-1). Arsenic mobilization can also be facilitated or worsened through such human activities as metal mining and groundwater abstraction and, in some cases, through use of arsenic-based pesticides in agriculture and wood preservation. Although some problems remain, heavy metal contamination has generally diminished in EU countries since 2000. A dramatic example of heavy metal contamination involved Flint, Michigan (United States of America). A decision to switch the city's drinking water supply in 2014 from Lake Huron to the Flint River, containing more corrosive water, released lead from leaded pipes in the city's water distribution system, with significant human health impacts (Masten *et al.* 2016).

9.5.6 Salinity

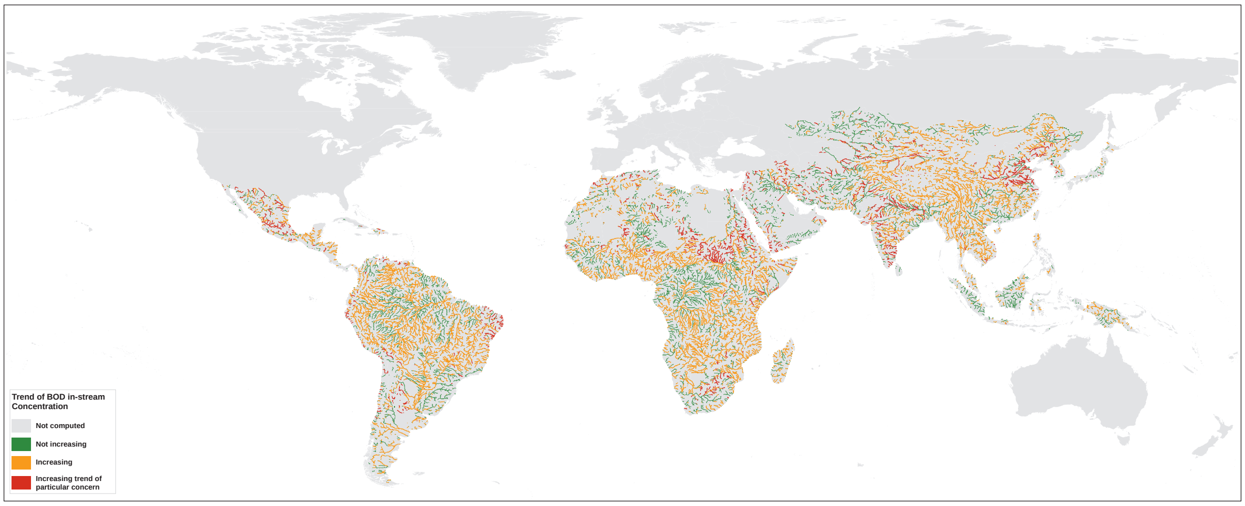
Increases in salinity, a measure of the quantity of dissolved minerals in freshwater, result from land-use changes, agricultural irrigation drainage, lake evaporation and seawater intrusion, usually most severe in arid and semi-arid regions (Vengosh 2003). Excess salinity renders the water unfit for many human uses, and most freshwater organisms have limited salinity tolerance (UNEP 2016e).

Salinity problems persist at various degrees in rivers throughout Africa, Asia and the Pacific, and Latin America, affecting agricultural irrigation as a result of accumulation of naturally occurring minerals in irrigation water, as well as industrial water uses (Foster *et al. 2018*; Annex 9-1), with surface-water salinization being a major issue in Central Asia. Saline water intrusion into coastal aquifers can result from over-abstraction and mismanagement, as well as sea level rise. Apart from sodium, waters with elevated levels of magnesium are emerging examples of water quality deterioration leading to environmental and food security constraints in several irrigation schemes (Qadir *et al.* 2018).

9.5.7 Contaminants of emerging concern

Water contaminants of emerging concern include certain human and veterinary pharmaceuticals, personal care products, insect repellents, antimicrobial disinfectants, flame retardants, detergent metabolites, microplastics and manufactured nanomaterials ('nanoparticles') (**Figure 9.13**; Kolpin *et al.* 2002; UNESCO 2016; Yuan *et al.* 2018). The United States Geological Survey detected such contaminants in a

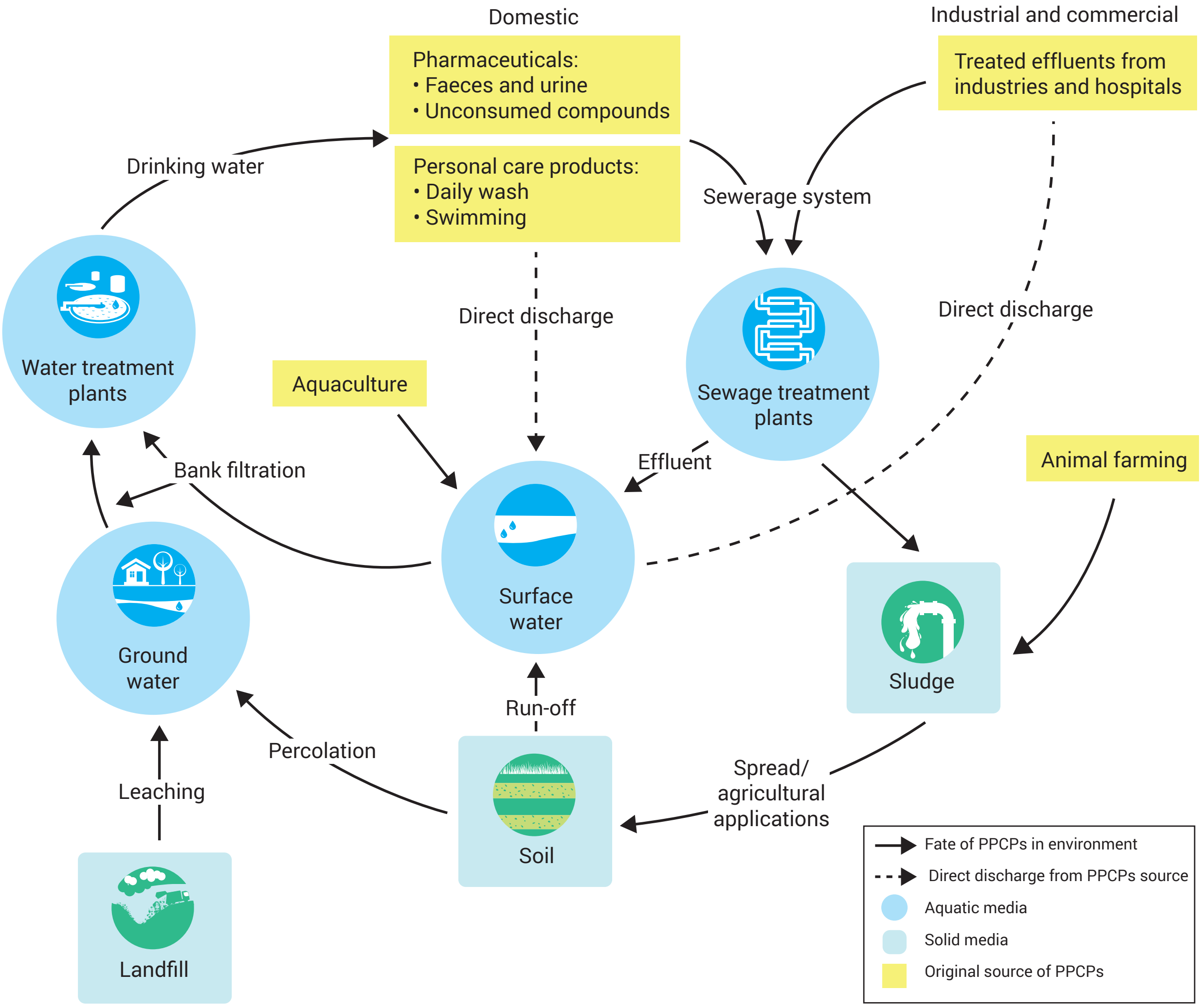
Figure 9.12: Model estimates of trends in biochemical oxygen demand (BOD) concentrations in rivers between 1990-1992 and 2008-2010



Orange and red river stretches: increasing concentrations between these two periods; red river stretches: increasing trend of concern.

Source: UNEP (2016e).

Figure 9.13: Source and pathways of pharmaceutical and personal care products (PPCPs) entering surface and groundwater, highlighting need for improved detection of commonly found PPCPs and their transformative products



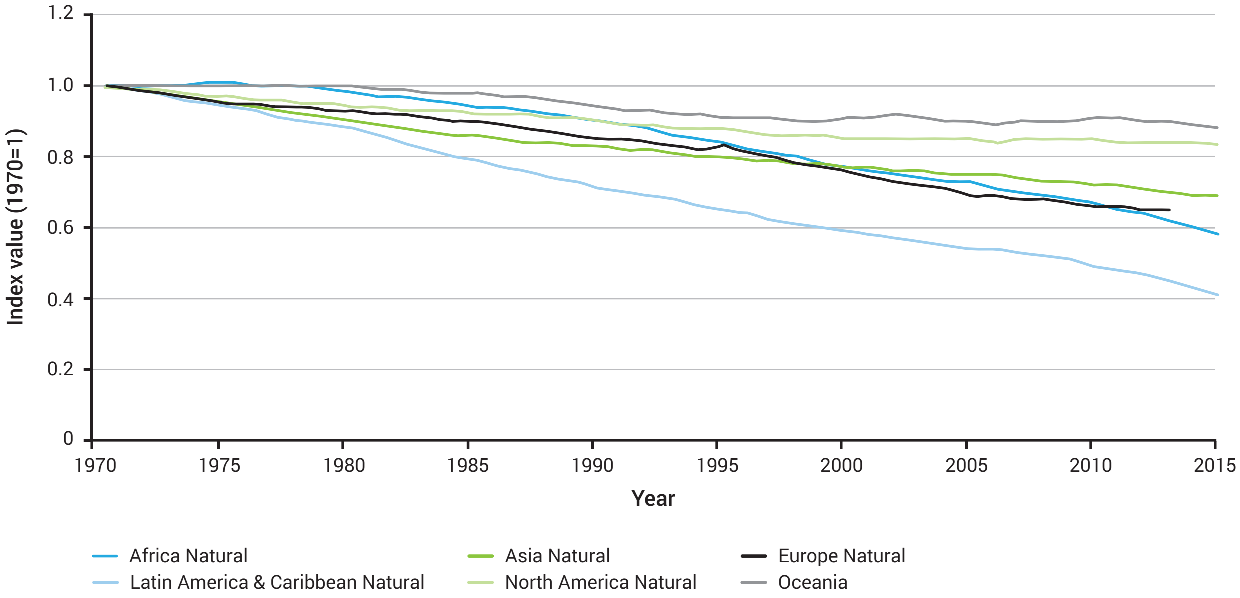
Source: Adapted from Petrović *et al.* (2003); Mompelat *et al.* (2009); Yang *et al.* (2017).

majority of sampled streams in the United States of America (Annex 9-1; Kolpin *et al.* 2002). They also were detected in all pan-European seas, as well as groundwater (Sui *et al*. 2015; Corada-Fernández *et al*. 2017). Used in fire retardants, oil and water repellents, furniture, waterproof clothes, takeaway containers and non-stick cookware, poly- and perfluoroalkyl substances (PFAS) were found in water systems serving 16 million people in 33 states in the United States of America between 2013 and 2015 (INTJ Input 2017). Conventional wastewater treatment is not effective in removing most of these contaminants from domestic and industrial wastewaters.

Many are endocrine-disrupting chemicals (EDCs), attributed partly to wastewater treatment plant overflows, particularly those with combined sewer systems. Being found in site-specific studies in Europe, the Asia and the Pacific region, Canada and the United States of America (Annex 9-1; Sui *et al.* 2015), their long-term human health impacts include fetal underdevelopment, child neurodevelopment and male infertility (Meeker 2012).

Micro- and nanoplastics (manufactured nanomaterials) resulting from microplastics in cosmetics, fragmentation of large plastic waste, tyre wear particles and laundering of synthetically based clothes are increasingly affecting freshwater and marine ecosystems (Annex 9-1; Horton *et al.* 2017). Of the 275 million (metric) tons of plastic waste generated by 192 countries in 2010, an estimated 4.8-12.7 million tons ended up in the oceans because of inadequate solid waste management. They are found worldwide in fresh and ocean waters, river and delta sediments, and in the stomachs of organisms ranging from zooplankton to whales (UNEP 2016g). Microplastics also can contain and absorb toxic chemicals. Electronic wastes also are of increasing concern because of their widespread abundance and unknown risks to surface- and groundwater quality.

Figure 9.14: Status and trends of the world's wetlands disaggregated by region



An index taking the total extent of wetland area in 1970 = 1, based upon a literature search.

Source: UNEP World Conservation Monitoring Centre (UNEP-WCMC) (2017).

9.5.8 Other water quality concerns

Groundwater pollution from oil and gas fracking activities, which use large quantities of chemicals and discharge large volumes of 'produced water', is problematic in the Americas (Osborn *et al*. 2011; Vengosh *et al.* 2014; Annex 9-1). Heavy metals, particulate matter, various organic chemicals, and EDCs are widely used in, or become by-products of, these oil and natural gas operations (Webb *et al.* 2017).

Lake acidification from atmospheric deposition of fossil fuel emissions causes problems in areas lacking soils or bedrock capable of buffering the emissions, including the north-east United States of America, south-east Canada and some Scandinavian regions. The situation is improving for affected lakes in the Adirondack Mountains region of the north-eastern United States of America, where sulphur and nitrogen oxide emissions have decreased since the 1970s (Annex 9-1; Driscoll *et al.* 2016).

Thermal pollution and radionuclides also represent water quality concerns. Thermal pollution, often resulting from using freshwater as a coolant in power plants and industrial manufacturing activities, can degrade water quality by changing ambient water temperature. The impacts can be multiple, including reducing the dissolved oxygen concentration while at the same time increasing the respiration rates of aquatic organisms using it. Some aquatic species populations may decrease because they cannot thrive or reproduce in waters at higher temperature, while others may increase, potentially changing the overall ecosystem dynamics of a waterbody. Radioactive contamination typically in the form of accidental releases of radionucleotides from nuclear activities have polluted inland freshwater systems in some areas, with negative implications for aquatic and other organisms, including humans, using these waterbodies (Echols, Meadows and Orazion 2009).

9.6 Freshwater ecosystems

9.6.1 Continuing loss of wetlands

Freshwater ecosystems (or inland wetlands) include marshes, swamps, peatlands, wetland forests, rivers, lakes, ponds and headwaters. They provide a range of provisioning, regulatory and supporting ecosystem services, including water and food supply, fodder and building materials, carbon and nutrient sequestration, unique habitats for endangered species (including migratory birds), flood- and drought-buffering capacity, ecotourism and cultural services (WWAP 2018). Although freshwater ecosystems only cover 0.8 per cent of Earth's surface, they support approximately 10 per cent of all known species (World Wide Fund For Nature [WWF] 2016), and are among the world's most biodiverse habitats. They are the ecosystems most affected by changing land use, particularly increasing urbanization and agricultural expansion.

Between 69 per cent and 75 per cent of wetlands worldwide are estimated to have been lost since 1900 due to rapid population growth, urbanization and agricultural expansion (Davidson 2014). The extent of the loss since 1970 differs notably across regions, the slowest loss rate being apparent in Oceania and North America. Levelling off of the loss rate in North America is due partly to the current national policy of "no net loss of wetlands" in the United States of America (United States Fish and Wildlife Service 1994). Although constructed wetlands can compensate to some degree for some natural wetland removal, they cannot typically provide the same level of ecosystem functioning, resilience and biodiversity, emphasizing the need for natural wetland protection and conservation (see Section 9.4).

Ecosystem services for all wetland types have been valued financially across a very wide range from US$300-US$887,828 per hectare per year, with a median value of US$12,163 (de

Groot *et al.* 2012). More specific assessments are needed. A recent valuation of swamp and floodplain ecosystem services attributed an average annual global value of US$25,000 per hectare per year, excluding the value of the land itself (Costanza *et al.* 2014). The estimated annual loss to the global economy from diminishing swamp and floodplain areas from 165 to 60 million ha between 1997-2011 is US$2.7 trillion (Costanza *et al.* 2014).

Although covering only 3 per cent of the planet's land surface, peatlands have a high carbon-sequestration value, hence they contain more carbon than all global forest biomass combined (Joosten 2015). The world's largest tropical peatland (Cuvette Centrale) covers an area of 145,500 km^2 in the Congo River basin, containing an estimated 30 gigatons of carbon accumulated over the past 11,000 years (Dargie *et al.* 2017). Draining peatland areas for agriculture (e.g. the large Indonesian and Malaysian palm oil plantations) breaks down the peat, rapidly emitting carbon as CO_2 and methane. About 15 per cent of peatlands worldwide have been drained in the last 40 years, contributing approximately 5 per cent of global carbon emissions (Joosten 2015).

As the drained peat decomposes quickly, it dries out, shrinks and subsides. Tropical coastal peatlands are subsiding by an average 5-7 cm/year, and thus become vulnerable to salinization during storm surges. During hot, dry periods, the fire hazard in peatlands is high (Jayachandran 2009), an example being extensive peat fires in Indonesia exacerbating brown-haze pollution of the whole Asian region in the summer of 2015 (Carmenta, Zabala and Phelps 2015).

The permafrost in boreal peatlands in and around the Arctic Circle is thawing and draining due to climate change, with effects on local and global carbon fluxes (Joosten 2015; Couture *et al.* 2018). Apart from additional emitted carbon, the permafrost thawing is damaging infrastructure and housing, affecting Arctic people's quality of life. For both tropical and boreal peatlands, the straightforward technical solution to addressing carbon emissions from drained peatlands is to rewet the peatland, bringing the water table back to the soil surface, as is currently being done at a large scale in Indonesia, Canada, Sweden and Switzerland (Zerbe *et al.* 2013).

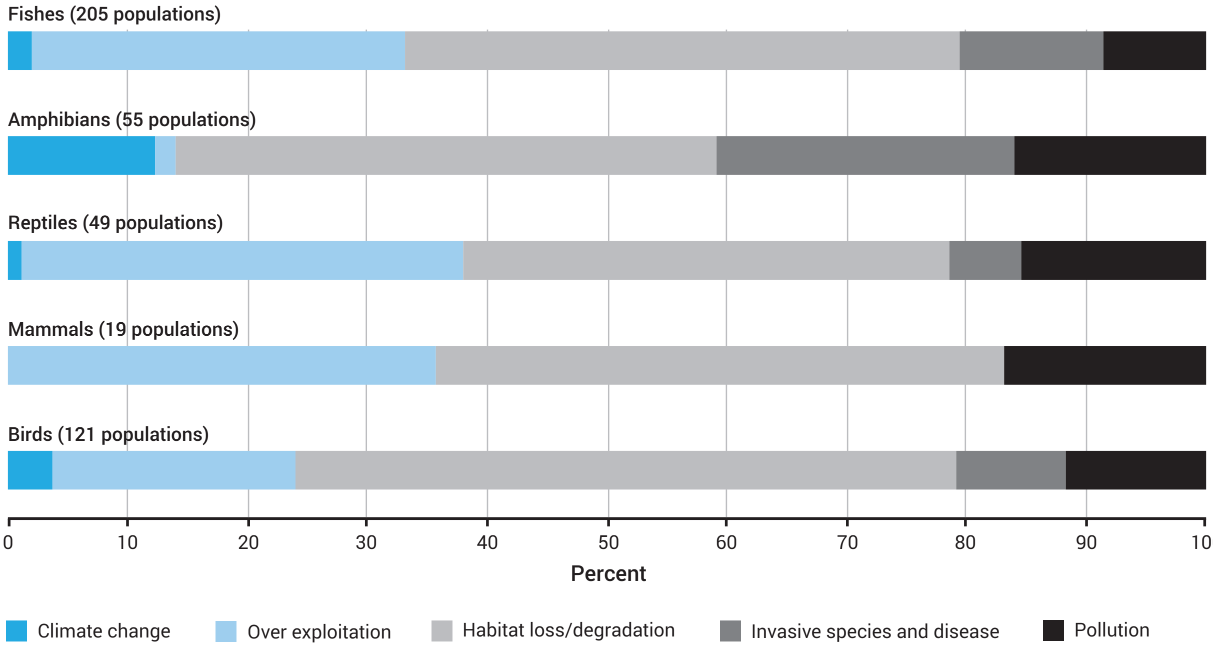
9.6.2 Biodiversity loss

There is evidence of significantly reduced abundance of populations of flora and fauna attributed to wetland loss and pollution impacts, particularly eutrophication, chemical and metal toxicity, and the hazards of plastic and other wastes (WWF 2016). Although wetlands have the capacity to filter and improve water quality, continuous breaking down of organic matter and other nutrients can lead to a tipping point in water quality, beyond which a wetland can no longer regenerate itself, with species assemblages potentially changing markedly.

Fragmentation of rivers through dam building and water diversion, with resultant wetland habitat losses and degradation, has a significant impact on fish populations, especially migratory and endemic fish species. Fish populations are also being overexploited for food. Amphibian species are experiencing dramatic declines through habitat loss, invasive species, disease and pollution, followed by climate change (WWF 2016) **(see Figure 9.15).** Reptiles and many bird species are deeply affected by loss of wetlands, while aquatic mammals such as otters also suffer local extinctions from habitat loss and overexploitation.

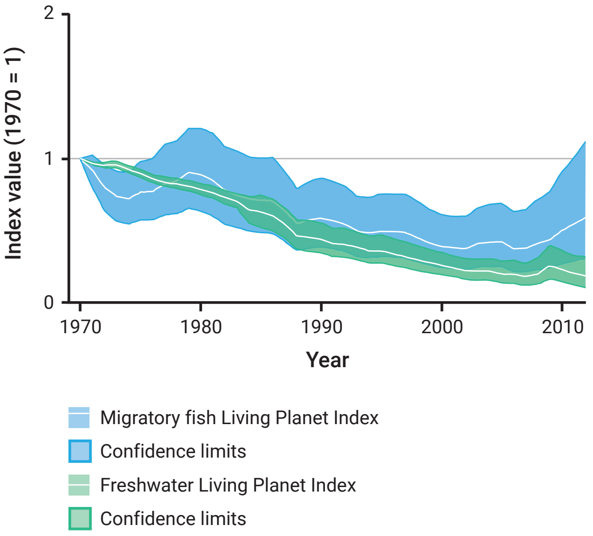
The Living Planet Index (LPI) measures population abundance trends of 881 freshwater species monitored worldwide across

Figure 9.15: Taxonomic differences in threat frequency for 449 declining freshwater populations in Living Planet Index (LPI) database



Source: WWF (2016).

Figure 9.16: Migratory fish from the Living Planet Index (LPI) exhibiting a decline of 41 per cent between 1970 and 2012, with a recent upturn, and freshwater LPI for 881 monitored freshwater species exhibiting an 81 per cent decline



Source: WWF (2016).

3,324 different populations (see chapter 6). Recent analyses indicate an 81 per cent decline in LPI in freshwater ecosystems between 1970 and 2012, the highest of any habitat type monitored using this index (WWF 2016).

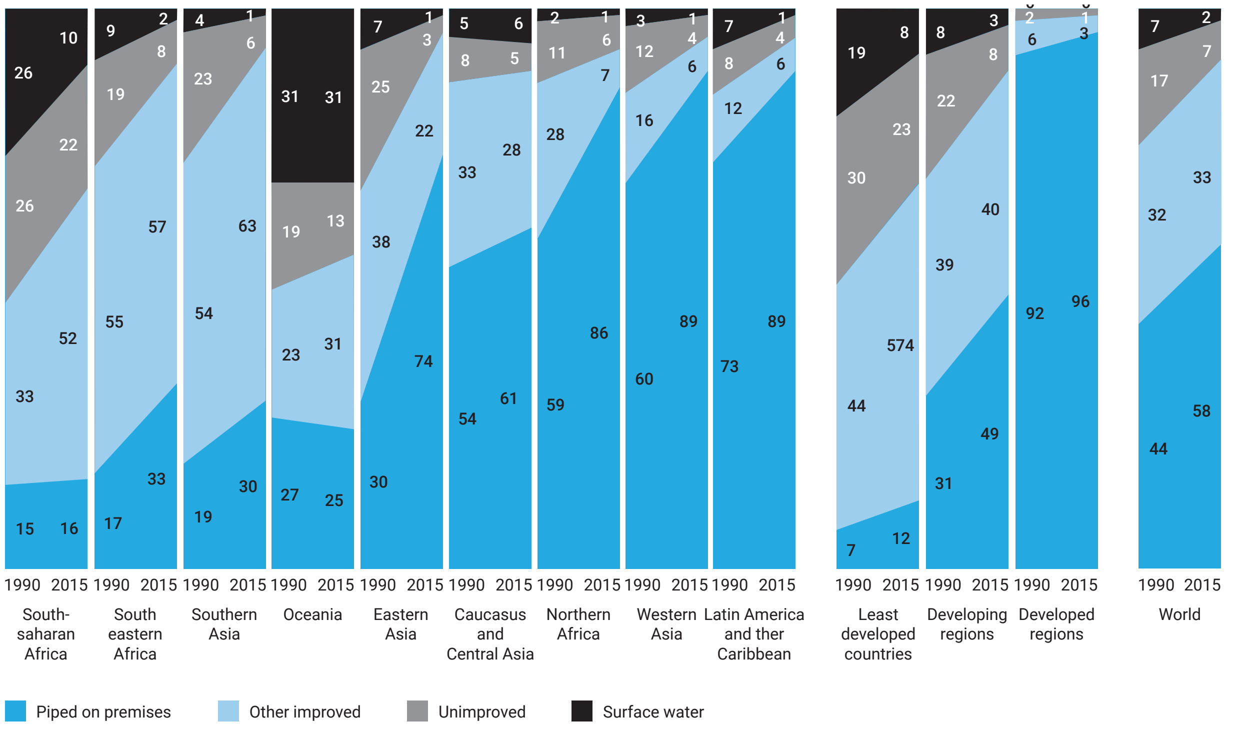
The LPI declined by 41 per cent over this period for migratory fish, based on measurement of over 162 fish species **(Figure 9.16)**. Some improvement is evident from 2008 onwards, in response to removing weirs, installing fish ladders, and improving the up- and downstream passage of migratory fish in many places. Migratory species of birds and mammal populations in certain managed wetlands are also starting to recover, in response to habitat conservation and restocking. In contrast, the decline in amphibian and invertebrate wetland species, including insects, is much higher (WWF 2016).

9 .7 Water infrastructure

9.7.1 Drinking water supply: treatment and distribution

Provision of safe, reliable drinking water is a continuing goal of development institutions, requiring modernization of ageing infrastructure and construction of new infrastructure. In many parts of the world, the original infrastructure is deteriorating, requiring upgrading. Provision of drinking water services has not kept pace with the rate of urbanization in many Latin American and Caribbean cities (UNEP 2016f; World Health Organization [WHO] and United Nations Children's Fund [UNICEF] 2016). The Millennium Development Goal (MDG) of halving the number of people without access to safe drinking water by 2015 was achieved by 2010, although progress was uneven across urban and rural populations in all regions (WHO and UNICEF 2015) **(Figure 9.17)**.

Figure 9.17: Variations in trends in drinking water supply coverage across regions



Source: WHO and UNICEF (2015).

In Asia and the Pacific, progress in provision of drinking water was significant, with 90 per cent of the population having access to improved water supply by 2015. Drinking water supply in Africa increased from 56 per cent in 1990 to 65 per cent in 2013, albeit mostly in urban areas, with 90 per cent of the urban population using improved water sources (UNEP 2016d).

There were significant improvements in access to drinking water in West Asia, with 89 per cent of the population having access to improved water supply by 2015. The reliability and continuity of service remains challenging, however, especially in conflict zones (UNEP 2016c; WHO and UNICEF 2016).

The relatively high quality of North American and Western European drinking water contributes to good public health, with these regions having some of the lowest rates of water-borne disease in the world. Most of the countries in these regions are party to the United Nations Economic Commission for Europe/ World Health Organization (WHO) Regional Office for Europe Protocol on Water and Health, and to the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes, a multilateral agreement committing countries to work actively to lower water-borne disease outbreaks (UNEP 2016a; UNEP 2016h).

Gender is a significant factor in water supply, with women and (mostly female) children continuing to carry the major burden and safety risks of acquiring and physically transporting water from source to place of use, particularly in developing countries, despite 1.5 billion more people gaining access to clean water since 2000 (WHO and UNICEF 2017; WHO and UNICEF 2012) **(Figure 9.18)**.

The water collection time burden and the physical labour involved have implications for the livelihoods and safety of women and girls. Time spent by school-age girls collecting water competes with schooling (UNICEF and WHO 2012). It also reduces the ability of women to participate in other pursuits. It represents a substantial economic drain. Women in India spend an estimated 150 million workdays per year collecting and carrying water, the equivalent of a national income loss of 10 billion rupees (approximately US$160 million per year). The positive impacts of women being able to spend time on other activities should be widely acknowledged, since economic surveys indicate they typically reinvest up to 90 per cent of their income in their families, improving family health and nutrition, and increasing access to schooling for their children (Unilever *et al.* 2015).

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Figure 9.18: Summary of global progress in providing basic drinking water services and disproportionate impact on women in areas still lacking access to basic drinking water services

Source: UNICEF and WHO (2012); WHO and UNICEF (2017).

9.7.2 Sanitation and wastewater treatment

Improved sanitation, including proper human waste treatment and disposal, is one of the most effective measures for improving public health globally (Sedlak 2014). It remains a challenge, however, in many parts of the world (**Figure 9.19**). Growing megacities, especially in Africa and Asia, do not have adequate sanitation services to accommodate population growth, contributing to open defecation and poor or non-existent wastewater treatment and disposal (UNEP 2016b; UNEP 2016d). Even in areas with improved sanitation, large-scale septic tank and leachfield use in many expanding urban centres affects downstream water supplies as well as groundwater quality.

Approximately 1.4 million people still die annually from treatable diseases associated with pathogen-polluted drinking water and inadequate sanitation, with many millions of others becoming ill (Lozano *et al.* 2013). An estimated 2.3 billion people still lacked access to improved sanitation in 2015. While almost all developed countries had achieved 'universal sanitation coverage' by 2015, only four of the nine developing regions met the sanitation target (Caucasus and Central Asia, East Asia, North Africa, West Asia). The population proportion served by improved sanitation was particularly low in parts of Oceania, sub-Saharan Africa and South Asia (WHO and UNICEF 2015).

There are significant inequalities in access to improved sanitation between rural and urban areas. About 82 per cent of the global urban population has access to improved sanitation, compared with only 51 per cent of the rural global population (WHO and UNICEF 2015). Public sanitary facilities tend to be regulated at local level in most countries. Where facilities are inadequate, they are often especially so for women and girls, including those located in markets, public transport stations and public event venues. Inadequate sanitation in schools has a deleterious effect on education, especially for girls. The problem is compounded for people living in slums and informal settlements lacking access to adequate drinking water and sanitation facilities, or to durable housing, sufficient living area and security of tenure.

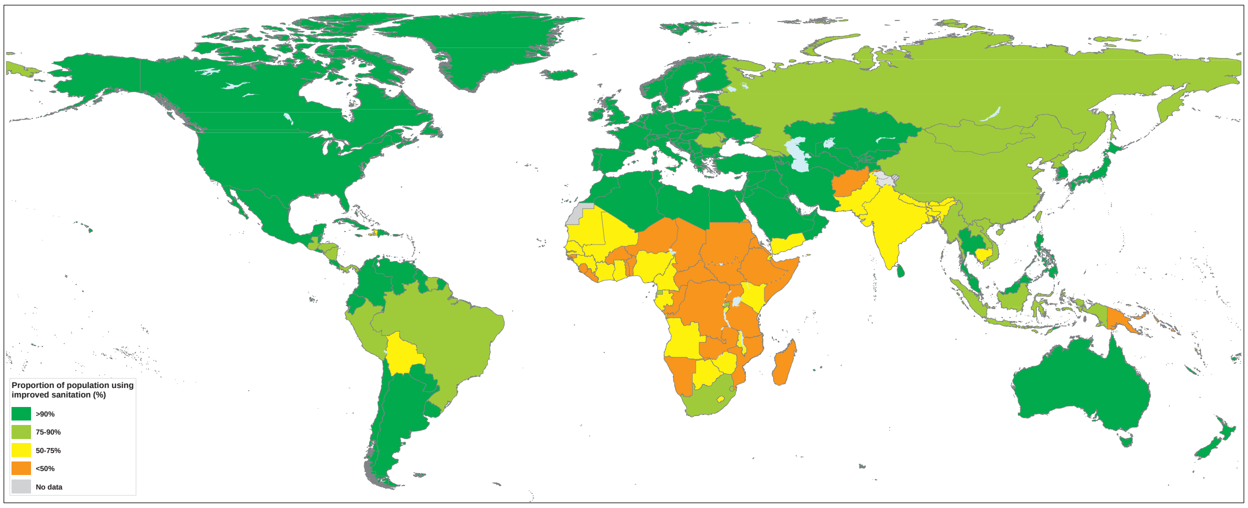
9.7.3 Dams and reservoirs for water storage and hydroelectric power

Many developing countries continue to construct dams to secure domestic water supply for communities, agricultural irrigation and hydroelectric power generation. Such multifunctional dams can also be operated to provide flood protection to downstream communities, as well as being sensitive to downstream ecological flow requirements (e.g. providing flow pulses to support fish spawning). Hydroelectric power is a key energy source, often critical to provide energy for drinking-water pumps, with additional growth potential evident in Latin America, Africa and Asia (Campuzano *et al.* 2014; UNEP 2016e). In addition, the use of reservoirs for pumped hydro-energy storage systems is increasingly being used to offset the fluctuating nature of other renewable sources of energy (Rehman, Al-Hadhrami and Alam 2015; Barbour *et al.* 2016) On the other hand, efforts to employ run-of-the-river hydroelectric power technologies have shown promise in the Amazon region in supplying electricity to rural communities, exhibiting fewer environmental impacts than traditional dams (Sánchez, Torres and Kalid 2015).

In recent years, dam construction in industrialized countries has slowed considerably. Many older dams are being decommissioned for economic (e.g. high dam operation and maintenance costs) and environmental reasons (e.g. effects on migratory fish, downstream ecosystems and sediment patterns) (O'Connor, Duda and Grant 2015; UNEP 2016e). Dam density nevertheless remains highest in industrialized countries (**Figure 9.20**).

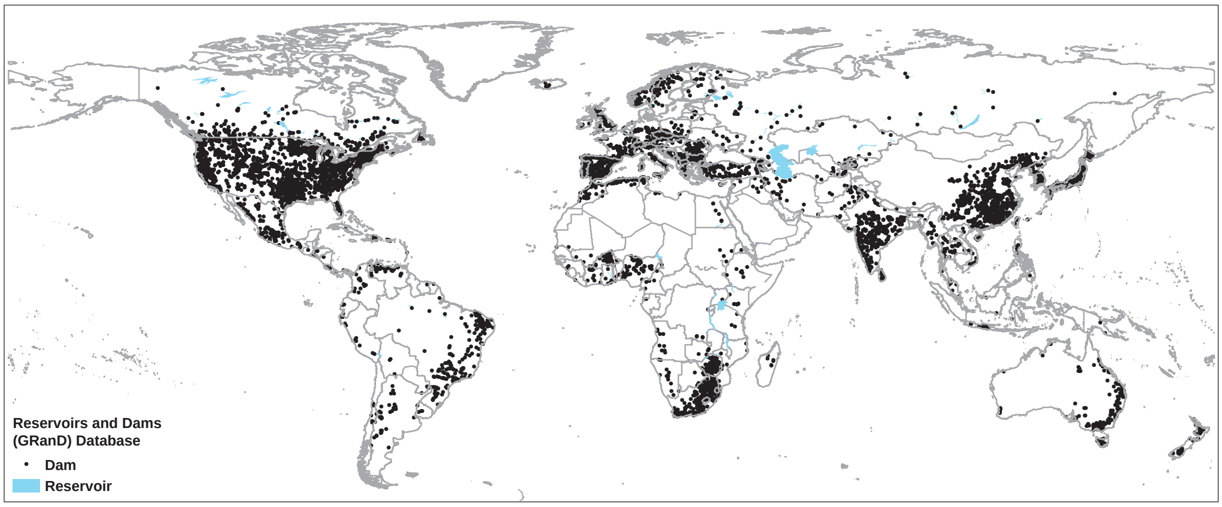
More than 1,270 dams have now been constructed across Africa for irrigation, hydroelectric power production and domestic water supply purposes, although only about 20 per cent of the potential to generate hydroelectric power is currently being utilized and lack of resources to properly maintain dams has resulted in reduced power generating capacity in some places. Increased dam construction in some locations (e.g. Ghana, Benin, Burkina Faso) has caused

Figure 9.19: Proportion of population using improved sanitation facilities in 2015



Source: WHO and UNICEF (2015).

Figure 9.20: Location of dams and reservoirs around the world. Data include dams associated with reservoirs that have a storage capacity of more than 0.1 km^3 and may not represent large dams and reservoirs that have been constructed in more recent years



Source: Lehner *et al.* (2011).

water contamination, irregular flows, methane emissions and degraded ecosystems, including increased sedimentation, and invasive aquatic plant and animal species (Zarfl *et al.* 2014; UNEP 2016d). Increased sediment trapping associated with reservoirs has been linked to subsidence in deltaic areas and reduced soil fertility, for example the White Volta delta (Boateng, Bray and Hooke 2012; Anthony 2015). Recent construction of large dams has generated significant controversy in many areas, including Africa (e.g. Grand Ethiopian Renaissance Dam; Yihdego, Khalil and Salem 2017), Turkey, the Balkans and the Mekong basin.

Drought is a major risk for hydroelectric power generation. Brazil experienced one of its most debilitating droughts ever in 2015, resulting in decreased reservoir water levels and flows, with many hydroelectric power facilities nearing zero capacity, and causing water shortages to several major Brazilian cities, including São Paulo (Poindexter 2015). The Brazilian example demonstrates the need to foresee conditions that must be dealt with by engineering systems while striving to find an even balance between guaranteeing water supplies and minimizing social or environmental costs.

9.8 Impacts

9.8.1 Human health

Contamination of water and food by faecal material as a result of poor sanitation and poor hygiene, leading to unsafe drinking water, is a major cause of gastrointestinal illness, particularly diarrhoea. Diseases and organisms associated with diarrhoea include cholera, typhoid, hepatitis A, giardia and cryptosporidium (Lozano *et al.* 2013).

The most important known viral cause of diarrhoea (rotavirus) is being reduced by vaccination programmes (Burnett *et al.* 2017). Open defecation also causes important parasitic diseases transmitted via contact with soil and water (e.g. ascaris, hookworm, water snails) (McCarty, Turkeltaub and Hotez 2014; Lo *et al.* 2017).

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While hygiene-related diseases have diminished greatly, deaths from diarrhoea still constituted the second most prevalent cause of death (about 13 per cent) in children aged one to four years in 2010 (Lozano *et al.* 2013). Sub-Saharan Africa and South Asia have the highest mortality rates associated with water, sanitation and hygiene (WHO 2017a). Chronic gastrointestinal infections, including those from parasites, cause disability, economic loss and cognitive impairment (Pinkerton *et al.* 2016; Lo *et al.* 2017). Because freshwater provides a habitat for mosquito-breeding, malaria and dengue fever exhibit an even higher disease burden for individuals residing near such habitats, although the situation is slowly improving (e.g. through widespread bed net use) (Ebi *et al.* 2016; Hemingway *et al.* 2016). Recent estimates of the burden of disease due to diarrheal diseases are summarized in **Figure 9.21**.

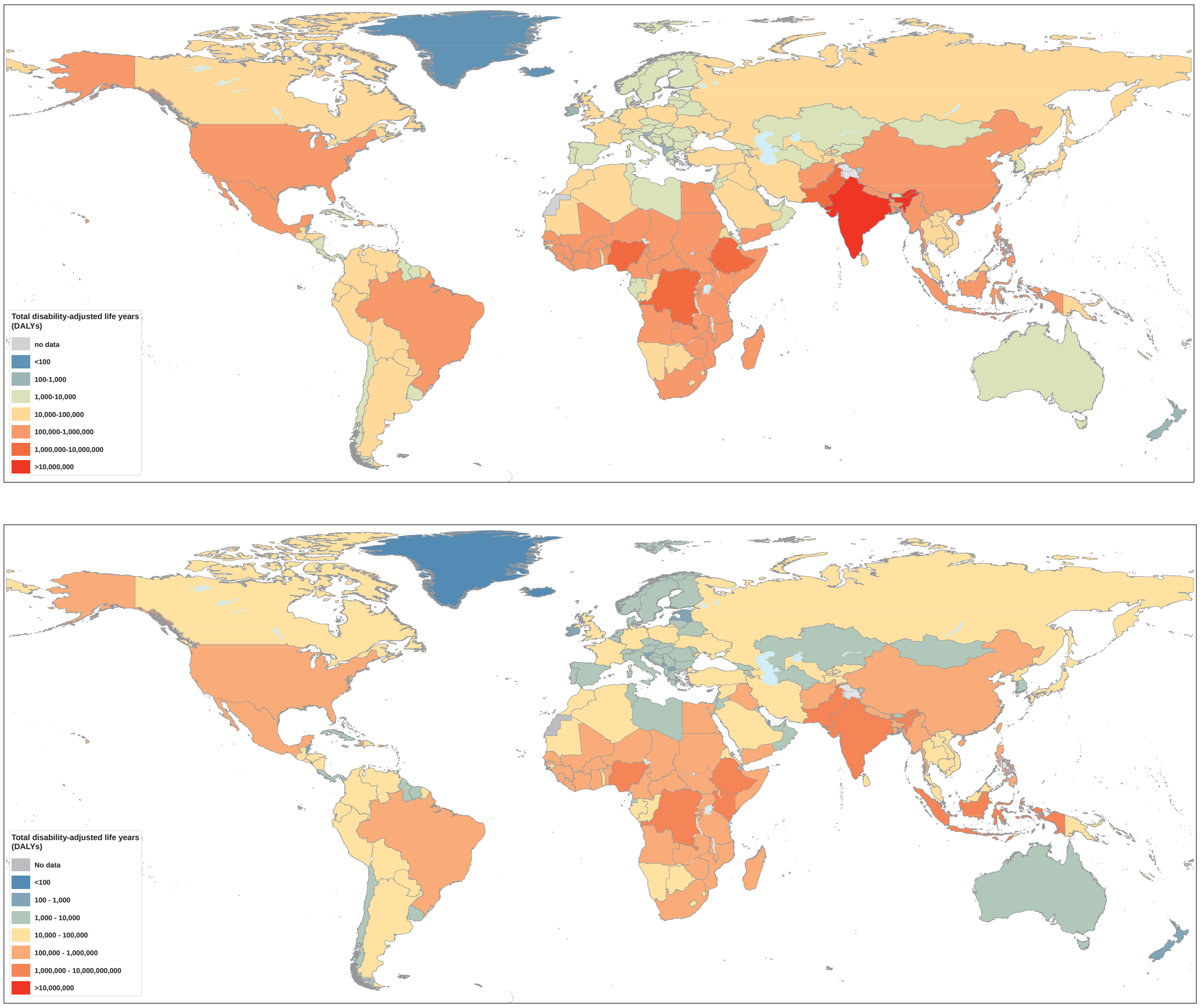
Health effects from water and sanitation-related diseases appear to vary by gender. Women may have less access to sanitation compared with men and spend more time in environments where open defecation has occurred, thus incurring a greater risk of parasite exposure. Gendered roles of fetching water and caring for young children, including disposing of their faeces, may further increase the exposure of women to sources of infection. Nevertheless, a recent systematic review and meta-analysis found that, overall, infectious diarrhoea was more common in males. Schistosomiasis was also more common in men, but cholera was more frequent in women (Sevilimedu *et al.* 2016).

Predicted hydrologic cycle changes associated with climate change may exacerbate the environmental health-related diseases, particularly diarrhoea (GBD 2015 DALYs and HALE Collaborators 2016; Mukabutera *et al.* 2016; Musengimana *et al.* 2016; Thiam *et al.* 2017).

9.8.2 Food security

Agricultural uses, primarily irrigation, account for 70 per cent of global water withdrawals (FAO 2016). Irrigated land, which accounted for 25 per cent of total cropland in 2012 (FAO 2016),

Figure 9.21: Morbidity (total disability-adjusted life years, DALYs) from diarrheal diseases (all ages) for females (upper graphic) and males (lower graphic), globally



Source: GBD 2015 DALYs and HALE Collaborators 2016 (2016).

nevertheless represented half of global crop production (FAO 2016). Climate change effects on temperature and rainfall patterns may drive additional irrigation demands, with water scarcity in many parts possibly limiting crop yields by 2070 (Elliott *et al.* 2014). Efforts are under way worldwide to address predicted hydrologic changes, including shifts to more water-efficient irrigation technologies, while trade of agricultural products provides opportunities for improving food security and adjusting to water scarcity through food imports (United Nations 2017).

The quality and availability of irrigation water and irrigated land are projected to decrease concomitantly, with potential negative effects on food security and human health. About 34.2 million ha of irrigated area has been affected by salinization (Mateo-Sagasta and Burke 2012), representing 10 per cent of total irrigated area globally (324 million ha) (FAO 2017). About 60 per cent of irrigation water does not reach crops due to leakage, spillage and evaporation (FAO 2017), with losses being especially high in developing countries with poor irrigation infrastructure. Improved irrigation efficiency could make a substantial difference. The Mediterranean region could save 35 per cent of its irrigation water through efficiency improvements (Fader *et al.* 2016).

Food security and associated water demands are and will be further stressed by a growing population (FAO 2016). Changing food preferences with rising incomes also increases water demands, with livestock products being more water-intensive than crops. Global meat and dairy consumption are projected to increase by 89 per cent and 81 per cent, respectively, during 2002-2050, with higher growth rates in developing countries (Thornton 2010). However, use of drought-tolerant or flood-tolerant crops will be critical to improving the productivity of the agricultural industry with changing water supply conditions (Zandalinas *et al.* 2018).

The virtual water trade concept (i.e. water embedded in traded products ranging from crops to manufactured goods) illustrates the comparative advantages of certain water uses, including agriculture and energy, in particular regions (Gilmont *et al.* 2018). If water is appropriately priced and allocated, market forces can lead to overall efficiency by capitalizing on these advantages, with virtual water trade redistributing water efficiently, and partially helping to address the disconnect between consumption and production impacts (Mekonnen and Hoekstra 2011; Vörösmarty *et al.* 2015). However, water is not always priced and valued appropriately: water embedded in food commodities is controlled by supply chain corporations and international trade that neither account for ecosystem services nor costs of watershed degradation. The problem lies in the lack of accounting systems for water stewardship in market systems and the practice of subsidies and taxes to keep food prices low (Allan *et al*. 2015; Allan and Matthews 2016). Farmers are faced with the resulting pressures on food prices, further disempowering them from managing and sustaining water and ecosystems (Allan and Matthews 2016).

9.8.3 Human safety and security

Degraded water quality, physical and economic water scarcity, and loss of freshwater ecosystem services have significant impacts on human safety and security. Floods and droughts affect ever-larger numbers of vulnerable people (IPCC 2014), with security and migration implications magnified in transboundary basins.

Transboundary cooperation in addressing water scarcity, floods and droughts is challenging, but can enable more effective, efficient management and adaptation by pooling available data, models, scenarios and resources, and enlarging the planning space for locating adaptation measures, including transboundary basins (United Nations Economic Commission for Europe and International Network of Basin Organizations 2015). Transboundary water management creates benefits in international trade, climate change adaptation, economic growth, food security, and improved governance and regional integration.

About 286 international transboundary river basins involving 151 countries pose challenging management problems (UNEP-DHI Partnership and UNEP 2016), as do transboundary lakes and reservoirs. Further, there are currently 366 identified transboundary aquifers and 226 transboundary 'groundwater bodies' underlying almost every nation (International Groundwater Resources Assessment Centre and United Nations Educational Scientific and Cultural Organization - International Hydrological Programme 2015). Even within federated countries (e.g. Australia, India, the United States of America), transboundary problems may be no less acute at a state/provincial level. Although water management has historically led to cooperative, rather than conflicting, outcomes, significant conflicts between stakeholders can still occur over the implementation of international and inter-state agreements. Intensification of water pollution and water scarcity can cause tensions within and between nations, though rarely being the sole trigger of conflict, since a complex mix of social and political conflicts, economic, demographic and environmental factors, and military occupation and water wars (hegemony) is typically the origin of such conflicts.

9.9 Policy responses

Human activities now dominate changes in the biosphere and functioning of the Earth system (Green *et al.* 2015; Vörösmarty, Meybeck and Pastore 2015; Vörösmarty *et al.* 2015), "causing complex, and frequently unwanted outcomes including unprecedented changes to global water circulation" (Bhaduri *et al*. 2016).

Box 9.3: Jordan faces a combined refugee and water crisis

Jordan is one of the world's most water-scarce countries, providing only 150 m^3 of water annually per person, much lower than the 1,000 m^3/capita level denoting water scarcity. Jordan also currently hosts over 717,000 Syrian and Iraqi refugees, adding to freshwater supply pressures. The formerly permanent lush Azraq Oasis in Jordan used to cover more than 6,000 ha, supporting a variety of plant and animal life, including migratory birds, as well as being the main water source for Jordan's capital city, Amman. However, it was almost completely dried out by 1990, due to overexploitation of the underlying aquifer. By 2017, there were over 35,000 refugees living in the Azraq refugee camp in the oasis (United Nations High Commissioner for Refugees [UNHCR] 2017), an unsustainable situation contributing to further water stress (Alhajahmad and Lockhart 2017).

In addition to many other challenges facing sustainability (Yihdego and Salem 2017), the 'Future We Want' adopted by the Member States of the United Nations in 2012 (Rio +20) recognizes that "water is at the core of sustainable development" (United Nations General Assembly 2012 [66/288]; UNESCO and WWAP 2015). Urgent local-scale actions to meet human water needs, however, may trigger increased regional and global environmental stress, and trade-offs (Bhaduri *et al.* 2016).

With the adoption of the 2030 Agenda for Sustainable Development, the United Nations General Assembly adopted a dedicated water goal (SDG 6), incorporating eight targets, in a holistic framework linking drinking water provision, sanitation, water-use efficiency, water quality and sustainability. The framework includes targets on integrated water resource management and transboundary cooperation, and this section examines a variety of global and regional governance approaches and policy responses to achieve them. The effectiveness of specific examples is explored in Chapter 16.

9.9.1 Expanding access to safe drinking water and sanitation (SDG Targets 6.1 and 6.2)

Many policy tools and responses proved successful in increasing access to potable water and improved sanitation during the MDG period (2000-2015). Though water-related investments and appropriate policy tools remain a top global priority, there are significant differences across nations and between rural and urban areas. Innovative technology has played an important role, with the introduction of ventilated improved pit latrines by the United Nations Children's Fund (UNICEF) in the 1980s, and small-bore hand pumps proving effective in many parts of Africa. An array of technologies will be needed to meet the unique circumstances of individual communities and the aggressive goals of SDG targets 6.1 and 6.2. Construction of water-harvesting cisterns in Brazilian rural areas reduced time spent collecting water by 90 per cent (Gomes and Heller 2016). Nonetheless, much still remains to be done to narrow the gaps in access identified in Section 9.7.1.

Funding mechanisms

Drinking water and sanitation are recognized as basic human rights with considerable economic benefits realized through investing in water and sanitation provisions. These benefits can be quantified as an overall estimated gain of 1.5 per cent of global gross domestic product (GDP) and a US$4.3 return for every dollar invested. This is attributable to reduced human health-care costs, greater workplace productivity and involvement through better access to relevant facilities (WHO 2017b).

Inadequate funding, corruption and rapid population growth still limit the achievement of SDG water and sanitation targets in African, Latin American and West Asian countries (UNEP 2016c; UNEP 2016d; UNEP 2016f). The funding gap is partly being addressed with allocation of domestic funds, for example in the 2003 Pan African Implementation and Partnership Conference on Water Declaration (African Union [AU] 2015; UNEP 2016d). Latin American governments have provided wider access to safe potable water for vulnerable populations using public funds (United Nations Economic Commission for Latin America and the Caribbean 2017; UNEP 2016f). WHO launched 'TrackFin', a methodology to track financing of water, sanitation and hygiene at national level, enabling more evidence-based policymaking (UN-Water and WHO 2015).

Market approaches as policy tools

Drinking water access and sanitation are generally considered public goods financed and/or provided through governmental or quasi-governmental entities. However, water pricing for users that reflect water treatment costs (both capital and operations) and incentivize water conservation (Giannakis *et al.* 2016), as well as private investment in water, have become more common in parts of the world, while remaining controversial in others (Harris *et al.* 2015).

Regulatory programmes

Regulatory programmes throughout North America, Europe and many parts of Asia rely on enforceable regulations at multiple governmental levels, focusing on delivery of safe drinking water through public utilities and appropriate wastewater treatment before discharging. Drinking-water standards protect public health, especially for vulnerable communities. A robust regulatory programme, focusing on enforceable municipal and specifically industrial discharge permits, could improve the policy approach in many parts of Africa, Asia and Latin America (Masson, Walter and Priester 2013; Aguilar-Barajas *et al.* 2015; UNEP 2016f).

9.9.2 Improving water quality (SDG Targets 6.3 and 15.1)

This target focuses on reducing pollution, halving the proportion of untreated wastewater, and increasing water recycling and reuse globally, as a means of improving water quality both for human uses, addressed by the WHO Drinking Water Safety Plan, and aquatic ecosystem health.

In the pan-European region, the basis for wastewater discharge limits, and wastewater collection, discharge and treatment, was set by regional legal instruments, including the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes (which has been open to accession to all United Nations member states since 2016), including its Protocol on Water and Health, and the European Union's Urban Wastewater Treatment Directive (WWAP 2017). The implementation of these at national level has achieved water quality benefits beyond the implementing countries.

Knowledge about the quantity and quality of pollutants, and where they are released into water, remains a prerequisite for addressing water pollution, and its impacts on human and environmental health (Sustainable Facilities Tool 2017). Some countries (or regions) address this goal by Pollutant Release and Transfer Registers (see United Nations Economic Commission for Europe [UNECE] 1998). On a pathway to a circular economy (SDG 12), however, full 'life cycle analysis' and management should be considered.

9.9.3 Water-use efficiency and responses to water scarcity (SDG target 6.4)

Addressing water scarcity requires reduction of use and improved water-use efficiency. This includes water reuse, shifts to less demanding crops and industries, water rationing, improved agricultural practices, and use of virtual water trade accounting for embedded water costs. However, even higher water-use efficiency sometimes does not meet community needs, requiring development of additional water sources (e.g. rainwater harvesting, desalinization, fog interception). Water is transferred across large distances and even between drainage basins in arid regions (e.g. Salem 2009). Management strategies and technological improvements outlined here address water scarcity and stress.

Water efficiency

Improved water efficiency is central to the water-food-energy nexus, considering factors such as climate change, population and land use (Fader *et al.* 2016). Water efficiency refers to reducing water wastage, in contrast to water conservation, which focuses on reducing water use. To this end, growing food demands require increased productivity per litre of water. Increased water efficiency could also result in reduced water use for energy production, assuming a gradual transition to non-fossil fuel energy sources. Rapid urbanization requires protection of water sources, reduction of reticulation losses and increased water in storage.

Efficiency gains across sectors and regions have been realized through technology and management improvements. As the largest global water user, agriculture represents the greatest potential in water-use efficiency. However, inadequate global data exist to accurately evaluate the overall state and trends of industrial and domestic water-use efficiency. The UN-Water Integrated Monitoring Initiative, initiated in 2014, attempts to address the water-related global monitoring gaps (UN-Water 2017). Existing data are informing the transition from the MDGs to the SDGs, but spatial distribution and frequency of measurements need to improve to strengthen water-resource monitoring, modelling and management.

Desalinization

Desalinization addresses water scarcity in arid regions and large coastal cities such as the Gaza Strip on the Mediterranean Sea (United Nations Office for the Coordination of Humanitarian Affairs [OCHA] 2017). About 60 per cent of global desalinization occurs in arid West Asian countries (e.g. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates) (Abuzeid 2014; Abuzeid *et al.* 2014; UNEP 2016c). It is also becoming more common in California, United States of America and eastern Australia, which are prone to recurrent drought years (Little 2015; UNEP 2016a).

Impacts of desalinization include large energy demands, associated greenhouse gas emission risks, the effects of heavy brine releases into coastal ecosystems (Jenkins *et al.* 2012), and entrainment of marine organisms in infrastructure (Dawoud and Al Mulla 2012). The desalinization industry is working to mitigate these impacts and advances in membrane efficiency and energy efficiency may reduce the cost of doing so by 20 per cent over the next five years, and up to 60 per cent over the next 20 years (Voutchkov 2016).

Water rationing

In water scarcity conditions, water authorities and governments must prioritize water allocations to specific sectors and users. While rationing mechanisms are usually determined by legal water rights, there may also be emergency measures protecting the public and the economy (see also **Box 9.4**).

Water reuse

Water reuse or reclamation is the concept of treating wastewater as a resource, rather than as variably contaminated waste discharged to the environment (UNESCO and WWAP 2015). Reclaimed water is most commonly used in developed countries for non-potable purposes (e.g. agriculture, landscape and park irrigation), thermal power plant cooling, industrial processes, and enhancing natural or artificial lakes and wetlands (UNEP 2016a; UNEP 2016c). Singapore uses recycled water for indirect potable use and for direct non-potable use. Windhoek (Namibia) uses it to recharge aquifers which thereafter feed water into the bulk water supply. Recycling treated wastewater provides multiple benefits by decreasing water diversions from sensitive ecosystems and reducing wastewater discharges to surface waters, in addition to being a dependable, locally controlled water supply and an opportunity to create green jobs.

Box 9.4: How cities face water scarcity

In late February 2018, Cape Town faced the prospect of 'Day Zero', a term coined for the date – then estimated to be 9 July – when the city was expected to run out of water, taps would run dry, and all municipal supply would be rerouted to emergency pickup points (Poplak 2018). This severe urban water scarcity in Cape Town is significant because it could have been the first major modern city to literally run out of municipal water if Day Zero was not averted by sufficient rainfall in the early winter season. There have been past cases of other cities such as Barcelona, regional capital of Catalonia, suffering its worst drought in 2008 since records began 60 years ago, with reservoirs down to a quarter of normal capacity (Keeley 2008). In 2015, Brazil's financial capital, São Paulo, one of the world's most populated cities (over 21.7 million inhabitants) experienced an ordeal similar to that of Cape Town when its main reservoir fell below 4 per cent capacity (Gerberg 2015).

The situation in Cape Town was caused by a three-year drought, considered to be a roughly 1-in-400-year hydrological event, resulting in the levels of the largest storage reservoir (Theewaterskloof Dam) to drop to 11 per cent of capacity (Poplak 2018). However, this proximate cause needs to be understood within a context of efforts to redress historical inequities and overcome institutional divides, and the need to innovate in the face of climate change.

Analysis of water consumption data from 400,000 households (Visser and Brühl 2018) illustrates how Capetonians rallied to avert Day Zero. Over four years of water consumption data indicate that usage by all domestic consumption brackets converged, with 63 per cent of households reaching the recommended target (under 10.5 kilolitres per month) in July 2017, and 30 per cent of households reaching the lower target of 6 kilolitres per household per month even before it came into effect in February 2018. Hence, Cape Town succeeded in halving its water consumption within three years, through a common vision and commitment by its people. A take-home message for Cape Town, and possibly for the world, is that "people's faith in each other's ability to safeguard the remaining water as part of a common pool resource, is critical" (Visser and Brühl 2018).

Using treated wastewater for agricultural irrigation can fertilize crops and benefit production while preventing nutrients and organic matter from entering freshwater systems. Insufficiently treated wastewater, however, can introduce pathogens, metals, excessive nutrients, POPs and emerging contaminants, and pose grave risks to workers and surrounding communities. Increased regulation, investments in treatment and risk assessments are essential for safe wastewater reuse (WHO 2006).

In West Asia, the United Arab Emirates currently reuses all treated wastewaters (290 million m^3 per annum), while Saudi Arabia reuses 166 million m^3. This reclaimed water is reused for agricultural production in Saudi Arabia's Al Hassa Oasis, after being mixed with groundwater (UNEP 2016c).

Effective management considers an entire watershed or basin as a socio-ecological system integrating across agriculture, forestry, industry, domestic and commercial uses in the ecosystem context. This has improved water availability, sanitation and wastewater treatment in many countries (SDG 6.5 and 6.6) (UNEP 2016a; UNEP 2016f; UNEP 2016h). European river basin management identifies various pressures, classifies monitoring results and enforces environmental objectives (e.g. International Commission for the Protection of the Danube River 2008). There has also been substantial progress in transboundary river basin management (e.g. European Commission 1992; European Commission 2000). Furthering surface and groundwater governance requires cooperation from multinational to local levels, supported by real-time data and information management (Cross *et al.* 2016).

9.9.4 Water governance (SDG Target 6.5)

The commonly accepted definition of integrated water resources management (IWRM) is "a process which promotes the coordinated development and management of water, land and related resources, to maximise economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems" (Global Water Partnership 2000). IWRM recognizes water both as a natural resource critical to society and economy and as an integral component of all ecosystems. While discussions over the merits of the IRWM approach continue (e.g. Jeffrey and Gearey 2006; Mukhtarov and Gerlak 2014), it is the major policy concept in place in over one hundred countries (Conca 2006; UNEP 2012a). IWRM is a progressive tool for reform, requiring strong political will for change, and contextual embedding in specific policy problems. However, it is not a panacea for all complexities of water governance (Ingram 2013). The Organisation for Economic Co-operation and Development (OECD) Principles of Water Governance have relevance to IWRM, emphasizing trust between stakeholders. A complementary approach recognizing the buffering capacity of lakes, wetlands and standing water systems is integrated lake basin management (ILBM), which focuses on "gradual, continuous and holistic improvement of basin governance by basin stakeholders" (Research Center for Sustainability and Environment-Shiga University and ILEC 2014).

The SDG 6.5 target calls upon all countries to implement IWRM at all levels by 2030, including through transboundary cooperation. Likely transboundary impacts on water resources are also often addressed in the procedures under the Espoo Convention and its Strategic Environmental Assessment (SEA) Protocol. To facilitate transboundary water system assessments and management, UN Environment, in collaboration with the Global Environment Facility (GEF) and partners, prepared a global assessment of the status of transboundary lakes, rivers, aquifers and small island groundwater systems, large marine ecosystems and open oceans, Transboundary Waters Assessment Programme (TWAP), (UNEP 2011). The International Groundwater Resources Assessment Centre (IGRAC), a TWAP partner, developed a groundwater information management system to tackle the paucity of standardized quantitative real-time data on key groundwater parameters, and underlined the lack of adequate groundwater governance at all levels.

Recent developments in international water law have significantly strengthened the legal basis regarding shared still (lentic) and flowing (lotic) surface waters and groundwaters. The 1997 Convention on the Law of the Non-navigational Uses of International Watercourses (UN Watercourses Convention) entered into force; the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes (UNECE Water Convention, as amended 2013) was opened to all United Nations member states; and the International Law Commission's 2008 Draft Articles on the Law of Transboundary Aquifers were commended to governments by the United Nations General Assembly. The two conventions, now operating in tandem at the global level, act as an important catalyst for the revision of existing agreements and negotiation of new river, lake and aquifer agreements at basin scale. Financing to support implementation of existing agreements remains a challenge. They are complemented by the United Nations Framework Convention on Climate Change, the Convention on Wetlands of International Importance especially as waterfowl habitat (Ramsar 2016) and the Convention on Biological Diversity (Convention on Biological Diversity [CBD] 1992), which address the protection of water-related ecosystems. Regional-level instruments for water management include the EU Water Framework Directive (European Union 2000).

9.9.5 Surface water-groundwater conjunctive management

Groundwater depletion can lead to streamflow depletion (Hunt 1999; Kendy and Bredehoeft 2006), while streamflow diversions can limit groundwater recharge. Managing these two sources as separate entities arises from limited knowledge of groundwater systems and their spatial and temporal relationships with surface waters, a situation that is no longer justifiable (Famiglietti 2014; McNutt 2014). Current experiences highlight the value of conjunctively managing and using surface and groundwater as 'one water' (Sticklor 2014), thereby buffering against both droughts and floods. Sound management would consider the potential long-term impact of sustained groundwater abstraction on groundwater-dependent ecosystems in arid or semi-arid areas.

Aquifer storage and recovery recharge (Pyne 1995) or managed aquifer recharge (Dillon *et al.* 2009) are becoming important tools to battle chronic water scarcity (e.g. in the state of Arizona, United States of America) (Lacher *et al.* 2014; Scanlon *et al.* 2016; Stefan and Ansems 2017). Underground water storage could play a significant role in semi-arid and arid parts of Africa (e.g. Botswana, South Africa) during episodic heavy rain events, and/or where surface-water storage and transfer options are exhausted (Tredoux, van der Merwe and Peters 2009; Bugan *et al.* 2016). Capture and storage of monsoon rains in depleted aquifers is being piloted in India (International Water Management Institute 2016).

Water sensitive urban design principles are critical to water-use efficiency, reuse (Wong 2011; Fisher-Jeffes, Carden and Armitage 2017) and flood management (Dai *et al.* 2018); for example, storing reclaimed storm and wastewater from the urban environment in aquifer(s). This approach is especially effective in mitigating subsidence of, and saline intrusion into, coastal city aquifers (Ortuño *et al.* 2010; Bugan *et al.* 2016).

Box 9.5 illustrates conjunctive development of surface and groundwater for Hermanus, a coastal town in South Africa, without inducing saline intrusion – a case aimed at mitigation of drought risks by balancing surface- and groundwater storage.

Box 9.5: Hermanus, near Cape Town, Western Cape Province, South Africa: A case study for conjunctive surface- and groundwater development and management

Groundwater was used for private housing developments and garden irrigation between 1971 and 2001. The greater Hermanus area water demand was met by the DeBos Dam (blue line, running concurrently with the purple total supply line in **Figure 9.22**). During 2002, 7,750 kilolitres/year of groundwater (green line) came online, with 24,191 kl/year added in 2009, as illustrated by the total supply (purple line) separating from the DeBos Dam inflow (blue line), with the groundwater addition (green line) keeping the supply line above the red demand line.

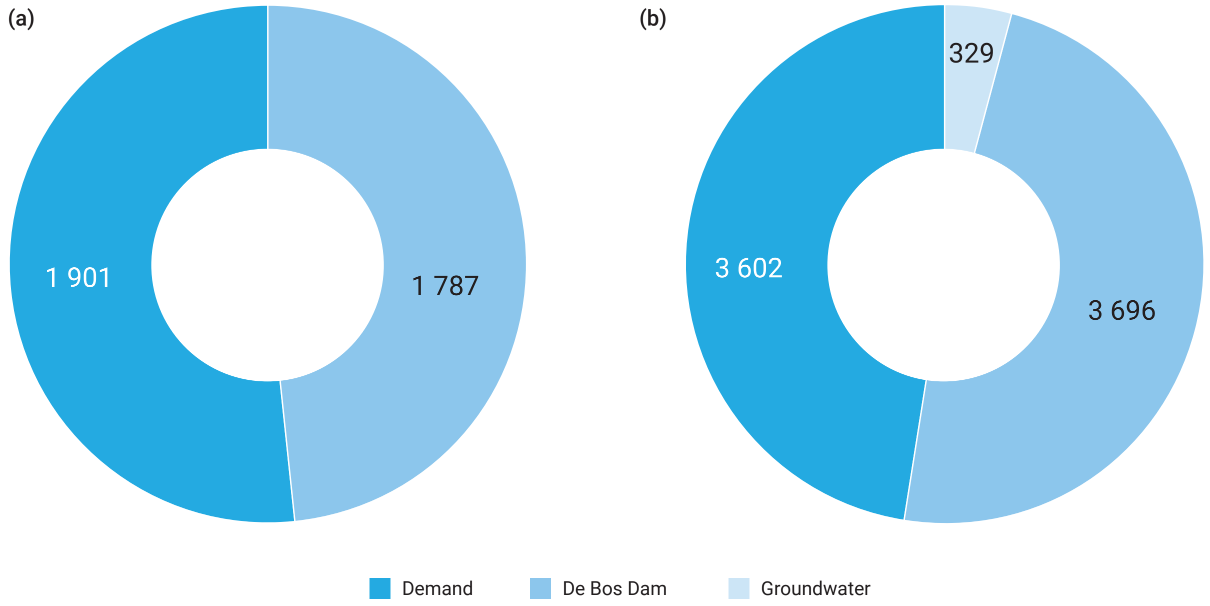
Groundwater augmentation was particularly effective in keeping supply above demand in 2010, when the DeBos Dam supply (blue line) could not meet it (red line). The water demand was met by surface-water supply from the dam, augmented by three well fields. Water restrictions were introduced in 2009 in anticipation of reduced surface-water supply and later lifted.

In contrast to other towns throughout the Western Cape Province suffering from severe drought, residents in the Greater Hermanus area were only advised on 27 February 2018 that it would be necessary to introduce Level 1B water restrictions from 1 March 2018; although water tariffs would only be increased once the dam had dropped to 40 per cent full level. The DeBos Dam was 46.5 per cent full on this date. (Overstrand Municipality 2018).

Figure 9.22: Hermanus Conjunctive Use

Source: Overstrand Municipality 2018.

Figure 9.23: Supply of and demand for water, Greater Hermanus, 1971-2001 (a) and 2002-2017 (b)



Source: Overstrand Municipality (2018).

Underlying successful conjunctive use is comprehensive monitoring, modelling and risk assessment of the aquifer and surface-water source(s), associated catchment areas and social systems in a learn-by-doing approach (Bidwell 2003). Managing aquifer resources requires a land-use zoning system based on aquifer vulnerability and constraints, to enable adequate abstraction rates and natural recharge (Cross *et al.* 2016).

Monitoring and management of the full water-use cycle by the private sector (e.g. agriculture and mining) is gaining recognition. Examples of stewardship programmes include Woolworths in South Africa (in partnership with WWF-South Africa, WWF-UK, the Alliance for Water Stewardship and Marks and Spencer); Coca-Cola and the United States Agency for International Development (USAID) Water and Development Alliance, H&M and WaterAid (Workers' Need Project in India), Unilever and Nestlé in Europe. The CEO Water Mandate (https://ceowatermandate.org) was instrumental in promoting the business benefits of water stewardship. This intersection between water governance, use, users, real-time monitoring, and modelling to inform evidence-based resource development and management is gaining momentum. In the fast-growing city of Bangalore, where 40 per cent of the water entering the system is lost to leakages, Water Supply and Sewerage Works formed an alliance with IBM and installed flow meters at several critical points in the water reticulation system. Data is being transmitted via GSM (Global System for Mobile communications) technology to a central Supervisory Control and Data Acquisition (SCADA) server to be transformed, aggregated and presented on a web interface and mobile application for end users.

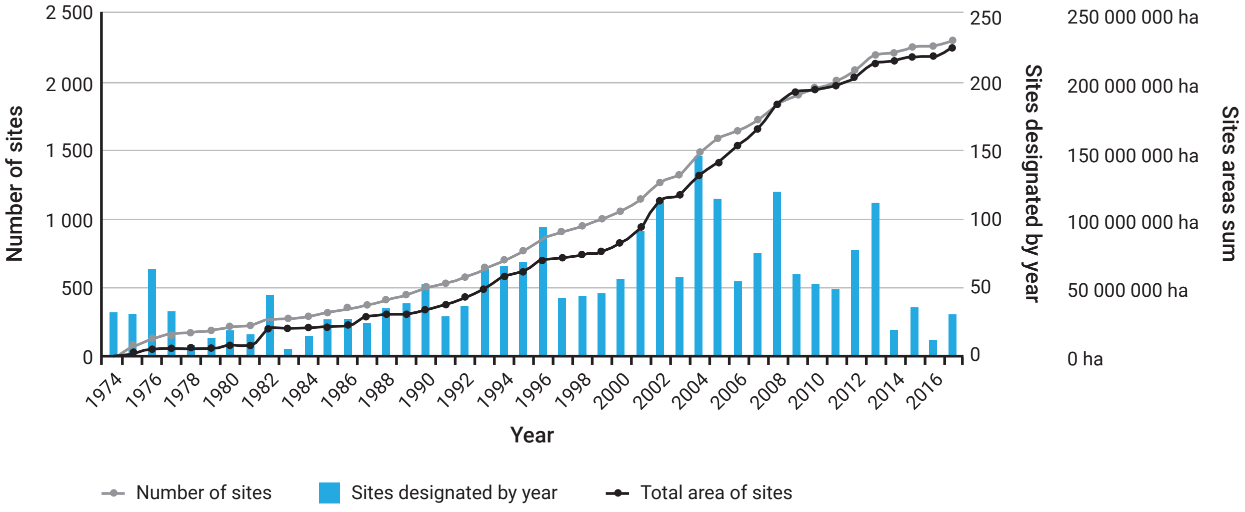
9.9.6 Protecting and restoring water ecosystems (SDG target 6.6)

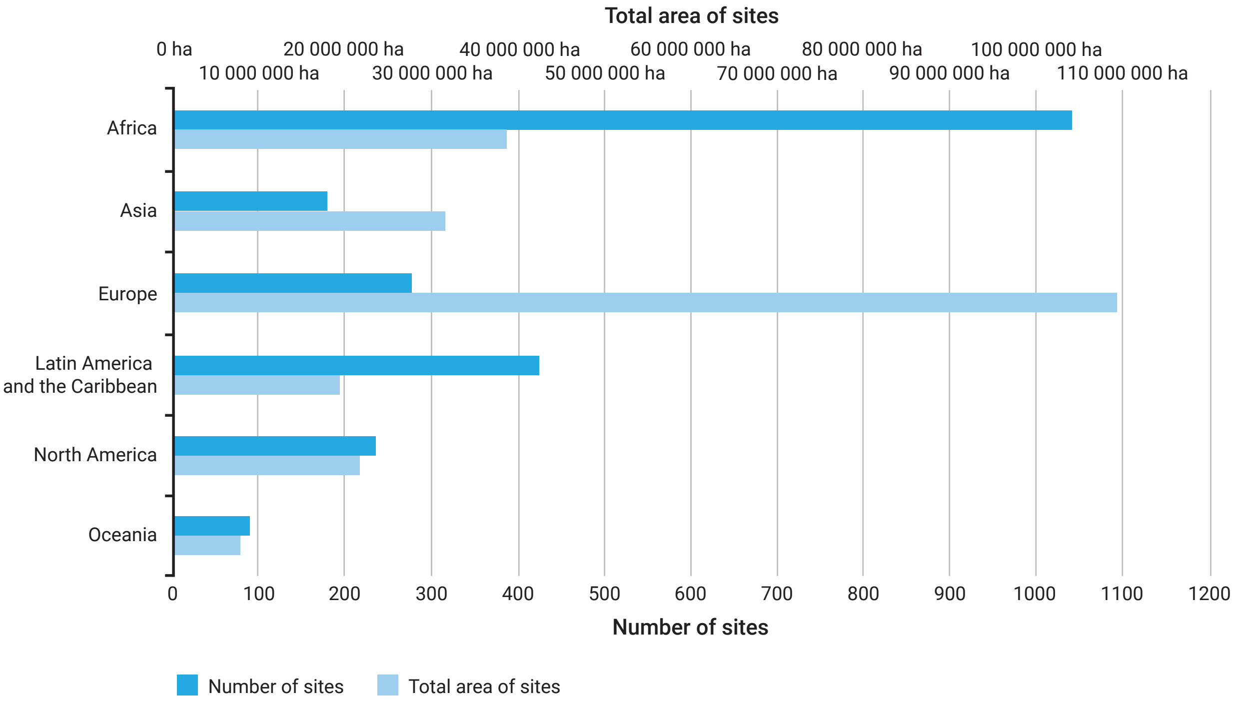
The importance of water-related ecosystems is specifically reflected in the water goal (SDG 6) and the terrestrial biodiversity goal (SDG 15). Target 6.6 aims "to protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes," emphasizing their crucial role in water cycle functions and watershed management.

SDG 6.6 monitors changes in the spatial extent of water-related ecosystems. Given wetland losses and associated biodiversity declines, many countries respond with natural wetland protection and management programmes and environmental flow requirements (e.g. Mexico's water reserves; South African National Water Act 1998 [Government of South Africa 1998]). River and wetland restoration and construction efforts are proceeding, including constructed wetlands for storm water treatment in Australia, recapturing floodplain areas in The Netherlands, and reconnecting wetlands and lakes to the main stem of the Yangtze River in China. Improved Earth observation data, combined with a classification methodology, enable countries to gain accurate pictures of their water-related ecosystems. However, there is a pressing need to extend on-the-ground monitoring of water cycle components and harmonize observations.

The Ramsar Convention on Wetlands (1971) is a multinational environmental agreement, devoted specifically to the conservation and wise use of wetlands. Each signatory country must designate and protect one or more "Wetlands of International Importance" (known as 'Ramsar sites'). As Contracting Parties to the Convention, 170 countries had designated 2,326 Ramsar sites by early 2018. The total wetland area protected by the Ramsar designation has increased from 81 million ha to almost 250 million ha since 2000 (**Figure 9.24**). New Ramsar sites designated in recent years tend to follow hydrological boundaries, to protect whole catchments and river basins (Ramsar 2018).

Figure 9.24: Ramsar sites designated by year and by region





Source: Ramsar (2018).

9.10 Conclusions

Widespread water scarcity is now an outcome of the connections and linkages between the hydrological cycle, unsustainable agriculture, and energy systems. At a local level, water is contested and plays a part in social conflicts and human migration decisions, against this backdrop of complex interlinkages. At a global level, the water cycle integrates the impacts of human activities, population growth and climate change. The deterioration of water quality across regions and continents threatens the health of people and ecosystems, while climate change is accelerating the water cycle and causing increased impacts on communities through storms, floods and droughts, extreme wildfires and landslides, as well as increasing dust and sandstorms in the most arid areas. Hence water, in addition to being a public good, is now becoming a risk multiplier for the health of people and of the planet.

However, the realization of SDG 6 (water) targets can be achieved through engaging public, private and non-governmental sectors, civil society and local actors, and by mutual reinforcement or trade-offs that also consider other interlinked SDG goals focused on poverty eradication (SDG 1), food security (SDG 2), health (SDG 3), gender equity (SDG 5), sustainable cities (SDG 11) and protection of biodiversity (SDGs 14 and 15).

Multinational environmental agreements (MEAs) governing water resources and water-related ecosystem management and climate change can support the embedding of integrated water resources management in the rules of law – through national and local legislation.

Effective, efficient and transparent water resources governance is required that includes improved collaboration and coordination between governments, technical institutions, non-governmental organizations and civil society towards improved monitoring and data quality, culminating in better hydrological and hydrogeological services, as discussed in the recent WMO conference held in May 2018 (World Meteorological Organization 2018). Increased investment in the scope and rigor of standardized water data is essential to improve policy and governance for sound water management.

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